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DETERMINATION OF THE RADIOLOGICAL IMPACT OF RADIOISOTOPE WASTE DISPOSAL

by

BEAK Consultants Limited

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Research report

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ABSTRACT

DETERMINATION OF THE RADIOLOGICAL IMPACT OF RADIOISOTOPE WASTE DISPOSAL

The Atomic Energy Control Board (AECB) controls the uses of radioisotopes and the management of wastes resulting from radioisotope use through licences. In most cases, wastes generated through the use of radioisotopes are required by licence condition to be sent to Chalk River Nuclear Laboratories for storage. In a few special cases where the amounts of radioisotope are very small, or where the activity of the radioisotope is very low, or where the radioisotope has a very short half-life, the radioisotope is permitted to be released to regular waste management systems such as municipal landfill, municipal incinerator or the municipal sewage system. Some examples of such cases are smoke detectors, and excretory products of patients undergoing nuclear medicine treatments. The AECB commissioned this study to determine the doses to individuals working in municipal waste management systems and to populations of cities where small amounts of radioisotopes are disposed of through the municipal waste management systems.

To carry out this study, it was necessary to select a city having a population size representative of many cities in Canada. Furthermore, it was necessary to select a city having as many different types of radioisotope users as possible. Also, it was necessary to select a city having all the possible municipal waste management systems. Finally, it was necessary to select a city having a well established data base on its waste management systems. Using this criteria, the Hamilton-Burlington area surrounding Hamilton Harbour was selected.

The pathways and dosimetry models were put into a computer spread sheet, to give the model flexibility so that it could be easily modified to model other cities. The model was developed using conservative assumptions and conservative estimates for some parameter values. The conservatism in these assumptions and parameter values means that the doses calculated by the model are over estimates. The model was used to calculate a collective dose for the population of the study area and doses to individuals within that population. The individual doses were doses to typical individuals of occupational critical groups and a general population critical group.

Within the occupational critical group, the maximum doses were calculated for the Hamilton sewage treatment plant sludge worker at 1.4E-6 Sv/a. If this individual were also a member of the critical group in the general population, the maximum dose would be 2.2E-6 Sv/a. Individual doses to the critical group within the general population were calculated as 7.7E-7 Sv/a for adults and 6.8E-8 Sv/a for infants. These compare to AECB regulatory limits of 5.0E-2 Sv/a per person for atomic radiation workers and 5.0E-3 Sv/a per person for the general public. The collective population dose for the study area was 1.37E-1 person-Sv/a or an average dose of 2.6E-7 Sv/a per person for the 525,000 population.

RÉSUMÉ

La Commission de contrôle de l'énergie atomique (CCEA) réglemente l'utilisation des radio-isotopes et la gestion des déchets qui en proviennent, en délivrant des permis. Dans la plupart des cas, l'une des conditions du permis stipule que les déchets de radio-isotopes doivent être envoyés aux Laboratoires nucléaires de Chalk River pour y être stockés. Dans quelques cas spéciaux où la quantité de radio-isotopes est minime, que leur activité est très faible ou que leur période est très courte, la CCEA permet au titulaire de permis de s'en débarrasser par les systèmes ordinaires de gestion de déchets, comme le remblayage dans les décharges municipales, l'incinérateur municipal ou le système d'égout municipal. Parmi ces cas spéciaux, il faut compter les détecteurs de fumée et les excrétions des malades qui subissent des traitements de médecine nucléaire. La CCEA a demandé que la présente étude soit faite afin de déterminer la dose aux personnes qui travaillent dans les systèmes municipaux de gestion de déchets et à la population urbaine dans des endroits où de petites quantités de radio-isotopes sont évacuées par les sytèmes municipaux de gestion de déchets.

Pour bien mener l'étude, il fallait choisir à la fois une ville dont la taille démographique était représentative de plusieurs villes canadiennes, qui comptait le plus d'utilisateurs différents de radio-isotopes possible, qui possédait le plus grand nombre de systèmes de gestion de déchets possible et qui avait une banque de données bien établie sur ses divers systèmes de gestion de déchets. À partir de ces critères, la région de Hamilton et de Burlington entourant le port de Hamilton a été sélectionnée.

Les modèles de voie d'acheminement et les modèles dosimétriques ont été imprimés sur des tableaux de ventilation informatiques afin d'assurer la flexibilité du modèle de façon à pouvoir le modifier par la suite pour l'adapter à d'autres villes. On a mis au point le modèle à partir de suppositions et d'estimations prudentes pour certaines valeurs paramétriques, c'est-à-dire que les doses calculées par le modèle dans ces cas sont surestimées. Le modèle a servi également pour calculer la dose collective de la population de la région à l'étude et la dose individuelle à l'intérieur de cette population. Les doses individuelles représentaient des doses à des

personnes types de groupes professionnels critiques et du groupe critique de la population en général.

Parmi le groupe professionnel critique, les doses maximales ont été évaluées à $1,4 \times 10^{-6}$ Sv/a pour un préposé aux boues de l'usine de traitement des eaux usées de Hamilton. Si cette personne faisait également partie du groupe critique dans la population en général, sa dose maximale serait de $2,2 \times 10^{-6}$ Sv/a. La dose individuelle estimée pour le groupe critique dans la population en général était de $7,7 \times 10^{-7}$ Sv/a pour les adultes et de $6,8 \times 10^{-8}$ Sv/a pour les enfants. Ces calculs sont comparables aux limites réglementaires que la CCEA a fixées à 5×10^{-2} Sv/a/personne pour les travailleurs sous rayonnements et à 5×10^{-3} Sv/a/personne pour le public en général. La dose collective de la population pour la région à l'étude était de $1,37 \times 10^{-1}$ personne-Sv/a, soit une dose moyenne de $2,6 \times 10^{-7}$ Sv/a/personne pour une population de 525 000 habitants.

SECTION 1

INTRODUCTION, OBJECTIVES AND DESCRIPTION OF STUDY

1.0 INTRODUCTION, OBJECTIVES AND DESCRIPTION OF STUDY

1.1 Introduction

Radioisotopes used in research, medicine and industry are generally controlled through licensing by the Atomic Energy Control Board. Licence conditions require management, handling and disposal of radioisotopes in a manner that avoids potential endangerment of human health. In most cases, this requires storage at specially licenced and managed waste facilities such as at Chalk River. However, in some special cases laboratories are authorized to dispose of small quantities of low level, short half-life materials in municipal sewage or garbage. Diagnostic or therapeutic radioisotopes also enter municipal sewage treatment systems when they are excreted by patients. In addition, there are a number of consumer products, such as smoke detectors, which contain radioisotopes and are usually disposed of in municipal garbage.

1.2 Objectives

The objective of this study is to determine the potential risk to human health from radioisotopes disposed of in municipal waste management systems. This requires several approaches:

- the definition of sources and radioisotopes of potential concern;
- the identification of the critical group of individuals who potentially receive the highest doses from the various waste management systems;
- identification of environmental dispersion and transport pathways for the radioisotopes disposed in municipal waste management systems;
- calculation of both collective dose and dose to the critical group; and
- assessment of the risks involved.

1.3 Overview of Study

1.3.1 Selection of the Study Area

The approach was to look at a city of approximately 500,000 population in which industrial, research, medical and domestic sources of radioisotopes, as well as municipal

waste management systems are typical of Canadian cities. This allows a realistic approach to impact assessment representing the relative risk to Canadian urban populations. This approach also allows the significance of the impact of radioisotope disposal in municipal waste treatment systems to be estimated. At the same time, it provides methods that can be applied to other urban populations should the need arise.

The study area chosen was the Hamilton-Burlington, Ontario urban area centred on Hamilton Harbour (Figure 1.1). This area was selected for the following reasons:

- the population of the area is approximately 500,000;
- the area has a variety of users of radioisotopes including, regular hospitals and a research and teaching hospital, a large university, a large industrial base and a source of consumer and household garbage;
- the area has municipal sewage treatment systems which drain into Hamilton Harbour, municipal landfills from which leachates enter the harbour either directly or via leachate collection and the municipal sewage treatment systems, and a municipal incinerator; and
- there is a reasonably complete and accessible existing data base on the urban area, potential radioisotope sources and probable pathways involved.

1.3.2 Sources of Radioisotopes

The next step in the study was to determine the sources and radioisotopes of potential concern. In an area like Hamilton-Burlington, there is a variety of potential sources. Atomic Energy Control Board (AECB) licencing records were reviewed to provide an initial list of radioisotope users. These plus contacts with researchers, medical laboratories and regulatory authorities, as well as a review of relevant literature, determined the radioisotopes to be considered. In order to maintain a manageable list of radioisotopes, radioisotopes which are returned to AECL for storage under licence requirements, those which are currently not being used in the study area, those with unmeasurably small quantities being used and those with extremely short half-lives were removed from the list.

There are at least six hospitals of concern in the study area (e.g, McMaster, Chedoke, St. Josephs, General, Joseph Brant and Henderson). They use radioisotopes for in vitro and

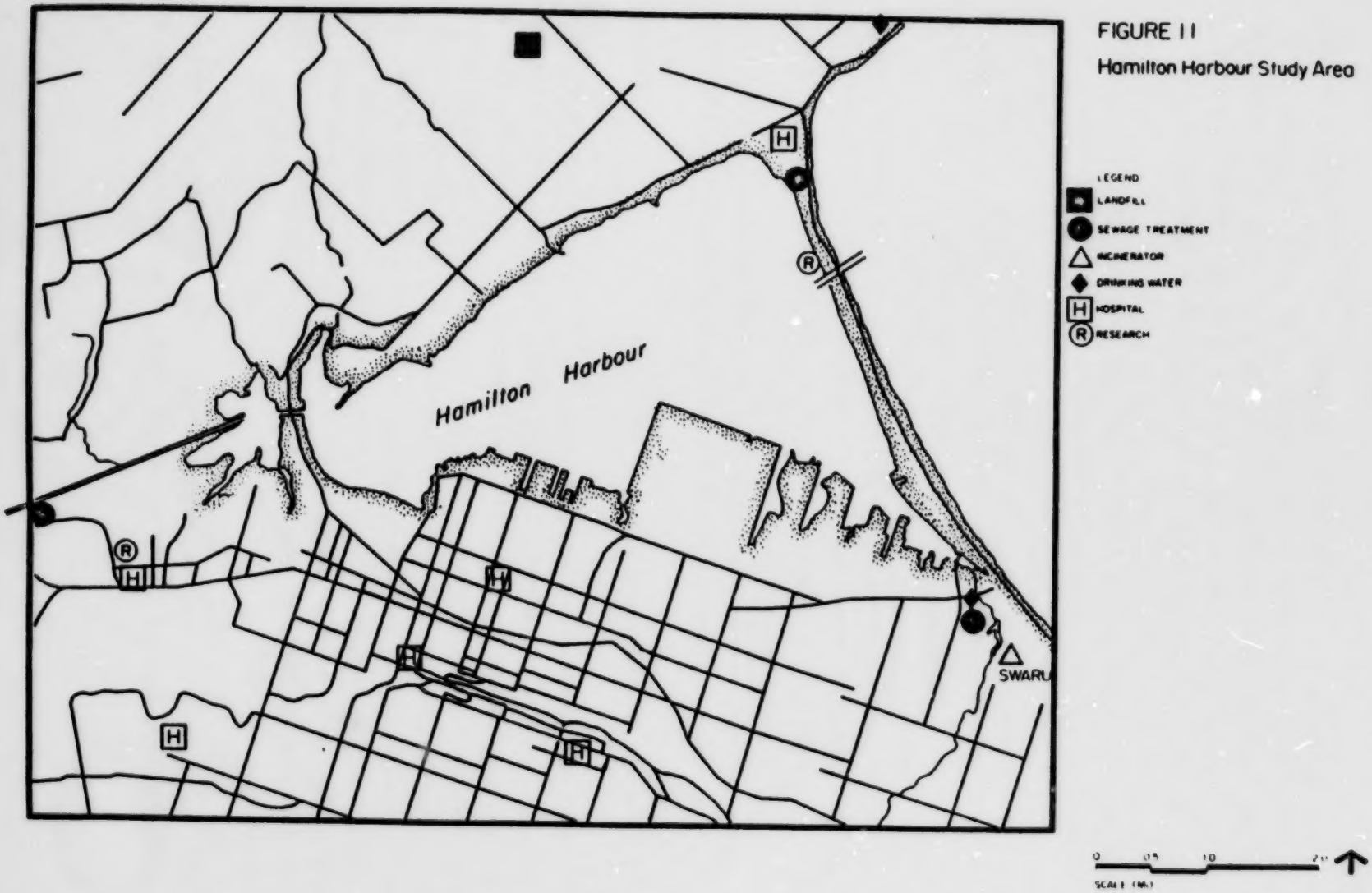


FIGURE 11

Hamilton Harbour Study Area

in vivo purposes. For tissue studies , radioisotopes such as Technetium -99m, Thallium -201, and Gallium -67 are used; they have short decay half times (e.g., hours to days). Other radioisotopes of concern are also manipulated in liquid form (Tritium, C-14). For patients, dye studies and therapeutic uses are the main application, with many decaying in the body and the rest being lost via the urine, feces and saliva (primarily to the sewer system).

McMaster University uses a variety of radioisotopes, including isotopes of carbon, phosphorus, silver, cobalt, manganese etc. These are used in the laboratory, field studies and in the reactor. Waste from the university and hospitals are in liquid and solid form. Some radioisotopes (particularly liquid) are shipped out of the region for storage (e.g., to Chalk River), removing them from consideration in this project.

In industry, a variety of radioisotopes are used. For example, the steel companies employ radioisotopes in thickness guages. A few radioisotopes are used in making paper products. Most of the used radioisotopes are returned to Chalk River for storage by AECL under license requirements.

In the home, radioisotopes such as Americium-241 are found in smoke detectors. After use, these detectors become solid waste.

1.3.3 Transport Pathways

General

Radioisotopes handled by municipal waste systems are disposed through two types of waste handling systems:

- sanitary sewer systems for liquid wastes, and
- solid waste collection systems.

Liquid wastes are transported to sewage treatment plants via sewer systems. Following treatment, the wastes are disposed of as liquid effluents, or as semi-solid sludges. The liquid effluents are released into Hamilton Harbour and the sludges either go to the landfill site (Burlington), or to a sludge incinerator (Hamilton). In Hamilton, the sludge incinerator ash is used as a portion of granular material for roads.

Solid wastes are collected by municipal garbage trucks and transported to regional collection points from which they are transported for incineration or final disposal.

Solid wastes from Hamilton are burned at the Solid Waste Reduction Unit (SWARU) incinerator. The resultant ash is landfilled. Depending on volumes of garbage and incinerator operation, some of the commercial or industrial bulk solid wastes may also be incinerated at SWARU. Due to maintenance and capacity problems, some of Hamilton's garbage is directly landfilled. Apartments in the Hamilton-Burlington area also incinerate most of their domestic solid wastes as do some of the hospitals.

Solid wastes from Burlington (as well as most of the rest of the Regional Municipality of Halton) are landfilled at the Burlington landfill site. The Hamilton landfill receives SWARU ash, the solid waste in excess of SWARU's capacity, and commercial, industrial and institutional solid waste handled independent of the municipal system. The landfill was located at Upper Ottawa Street (Figure 1.1) until it was closed due to capacity constraints. Although the current Hamilton landfill site is outside of the study area, we consider the Upper Ottawa Street Landfill site to still be in operation for purposes of this study. Leachates from both the Upper Ottawa and Burlington landfill sites enter Hamilton Harbour either through the ground or surface waters or via the sewage treatment plants.

Transport Through Sewer System

For all radioisotopes, adsorption to the sides of sewers, volatilization, and decay during transit are mechanisms which reduce the amount of radioisotopes discharged by hospitals and other sources from reaching the wastewater treatment plant. Dilution by both non-radioisotope sewage and storm waters also significantly reduces the radioisotope concentration in sewage prior to reaching the waste treatment plant. Volatilization and decay can be estimated, knowing transit times; adsorption and dilution are difficult to estimate. Radioisotopes which decay can be carried to the atmosphere through man-hole covers and impact the nearby population.

Wastewater Treatment Plant (WWTP)

The sludge from the grit chamber is primarily sands and gravels. Primary clarifier sludge is mostly inorganic, while secondary clarifier sludge is mainly organic material (bacteria, fungi, biopolymers etc.). The sludge is either incinerated, spread as an agricultural fertilizer, or disposed to landfill.

Landfill

Solid waste which accumulates in the landfill is derived from several sources - municipal solid waste, wastewater treatment plant wastes (digester sludge; clarifier sludge, incinerator residues), municipal incinerator residues and liquid wastes. In the landfill, the radioisotopes may be subjected to leaching action and transported through groundwater pathways, eroded to the atmosphere or remain in the landfill.

Leaching potential can be assessed in several ways. The key variable is the source of the material. If it is solid matrix (e.g., fused into a solid formed in an incinerator), little leaching is expected. If it is adsorbed to solids (e.g., adsorbed to swabs from hospital), leaching potential is great. Leaching potential was also assessed from the literature. Studies using lysimeters or laboratory scale tests give some information. Groundwater concentrations observed in and near existing landfills also give information.

In the groundwater, redox potential and pH are two master variables which can be used to assess transport potential. Adsorption onto particulates will retard transport. Where literature data are sparse, principles of chemical similarity can be used to estimate transport properties of particular radioisotopes.

Incineration

Three kinds of incinerators exist in the study area: the municipal incinerator (SWARU), the WWTP sludge incinerator and apartment incinerators. In Hamilton, the municipal waste incinerator, SWARU, burns mainly household garbage. The WWTP incinerator burns anaerobic digester sludge after conditioning. Apartment incinerators burn domestic wastes only. From incincerators, solid residues (to landfill), gases and liquid wastes (to waste water treatment) are all expected partitioning pathways.

Surface Hydrological Pathways

Effluents from the Hamilton and Burlington Waste Water Treatment Plants discharge to Hamilton Harbour. Leachates from the Upper Ottawa Street Landfill which reach Red Hill Creek enter the Harbour. Leachates from the Burlington landfill site enter the harbour primarily through the leachate collectors and the waste water treatment plant. Harbour water exchanges with Lake Ontario. Lake Ontario water is the source of drinking water for the Cities of Hamilton and Burlington, and for industrial finishing water. All exchange flows between the Harbour and Lake Ontario rates and runoff from the water shed have been well established (e.g., Snodgrass, 1981; Klapwijk and Snodgrass, 1985). Recreational uses of the harbour are mainly sailing while those for Lake Ontario are swimming, sailing and fishing.

Radioisotopes discharged to the harbour do not act conservatively because adsorption onto and settling of particles remove some radioisotopes to the sediments while other radioisotopes may volatilize to the atmosphere.

Atmospheric Pathways

Radioisotopes from the landfill and the incinerators will be transported primarily through atmospheric pathways. Gases and particles are emitted through the stack (incinerator) while degassing and particle erosion are the main removal mechanisms from the landfill.

1.3.4 Food Chain Transport and Dosimetry

Transportation pathways were modelled and dosimetry determined for occupational receptor groups (municipal waste workers), the integrated (collective) population of the study area, and a critical group in this general population. The critical group individuals are defined as those workers who stand the greatest risk for exposure from radioisotopes disposed of in municipal waste. These workers are especially important since unlike radioisotope laboratory personnel they do not wear dosimeters and are unaware of the potential hazards. It is thus essential to ensure their safety.

The most important contribution of airborne radioisotopes to the internal human dose is usually by direct inhalation of contaminated air.

Plants take up radioisotopes from the surface soil and from direct atmospheric fallout. Some of the radioisotopes taken up by crop plants, such as garden vegetables and fruit trees, are ingested by people as they consume plant produce. The air-crop and air-soil-crop pathways are excluded from this analysis, since agricultural areas are distant from atmospheric sources of radioisotopes and food production in the urban area is not expected to provide a significant portion of the local diet.

Fish take up radioisotopes from contaminated water as it crosses their gills, and by consuming other aquatic organisms. Some of these radioisotopes are ingested by people as they consume fish meat. Water .o fish transfer, or bioconcentration factors, have been determined from empirical measurement of radioisotope concentrations in water and fish (Thompson et al., 1972; IAEA, 1982; NRCC, 1980). These data were used to calculate radioisotope concentrations in fish from Hamilton Harbour.

Inhalation and ingestion pathways contribute to human internal dose. Internal dose estimates have been based on the quantity of water or fish consumed and air inhaled per person , the radioisotope concentration in the water, fish and air and internal dose conversion factors. The sum over all pathways and all radioisotopes gives the total individual dose from all internal radioisotopes. Since internal distribution and retention of radioisotopes differs between infants (up to 1 year) and adults, Johnson and Dunford (1983) have tabulated dose conversion factors for both age groups. Their factors are used in the current study.

Radioisotopes external to the body, in air or water, and on the ground, can also contribute to the radiation dose received. However, people are not continuously exposed to such external radiation sources. The external dose depends on the duration of exposure to the source (e.g., time spent swimming in contaminated water), radioisotope concentrations (in air, soil or water), and external dose conversion factors. External dose conversion factors were taken from Kocher (1981, 1983).

The occupational critical groups are identified by analysing work habits and human exposure in waste management systems based on interviews and site investigations at these locations. These workers include those individuals likely to receive the greatest radiation exposure. The critical group in the general public is the group of individuals likely to receive the highest doses through non-occupational means.

Collective dose calculations are performed for the population of the urban Hamilton-Burlington area. Annual collective and critical group doses arising from each disposal practice are calculated. The disposal practices resulting in the greatest contribution to annual exposure are identified.

SECTION 2

BASIC CONCEPTS

2.0 BASIC CONCEPTS

At present in Canada and throughout the world, a variety of radioisotopes are being produced for commercial use. These isotopes, numbering in the hundreds, are used for a variety of purposes ranging from ionization sources in consumer products such as smoke detectors, fluorescent light starters and static eliminators to medical pharmaceuticals used principally for diagnostic purposes. After these items have, as in the case of consumer products, worn out or broken they are often disposed of in municipal garbage. Similarly, radiopharmaceuticals pass through the body of patients and enter the sanitary sewage system. Once the radioisotopes have entered the municipal garbage or sewage systems they undergo a series of treatment and disposal steps during which employees in the waste handling system may be exposed to ionizing radiation originating from these radioisotopes. After treatment and/or disposal, depending upon their chemical properties, some of the radioisotopes may enter local ecosystem circulation and contribute to a collective dose to the local population.

Studies that have been carried out in other countries (e.g., Belanger et al., 1979) have suggested that the dose from individual incidental commercial sources such as smoke detectors is very small and does not require regulation. No studies have been done, however, in which all sources have been considered together and the total of their effect calculated on both their doses to individuals in critical occupational or public groups and the collective population.

The approach of this study is to select a cross-section of the most commonly used radioisotopes and follow these through all significant exposure pathways in order to determine if the combined dose received by waste handlers and members of the general public is at an acceptably low level. This is done in this study through the examination of incidental radioactive waste disposal practices in Hamilton/Burlington, a city considered for the purposes of this study to be typical of a medium sized Canadian city. The selection of Hamilton/Burlington allows an evaluation to be made of doses received as a consequence of municipal waste incineration, landfilling and sewage treatment originating from a variety of hospital, industry, residential and university uses.

Through an examination of the behaviour of each radioisotope as it passes through a given waste treatment technology, the effective dose equivalent received by the critical workers (most likely to be exposed to the highest annual dose by virtue of their proximity to the particular radioisotopes and their work habits) is calculated. This study also calculates the dose to critical members of the general public who may work or live in proximity to any particular waste handling facility. Dose to individuals such as hospital workers licenced to handle radioisotopes or the patients to which these radioisotopes may be administered for therapeutic purposes are not considered.

This study attempts to calculate what may be considered the most probable dose based upon our knowledge of both the chemical and physical behaviour of the radioisotopes investigated and the dosimetric models available for these same radioisotopes. Where good data were judged to be not available, assumptions on release rates or exposure levels were made in a conservative manner so that resultant dose estimates are most likely to err on the high side.

Based upon the results presented in this study and the data interpreted in light of the assumptions made, the regulatory agencies will be in a better position to determine the acceptability of the practices currently in use for the handling and disposal of incidental radioactive waste.

SECTION 3

RADIOISOTOPES CONSIDERED

3.0 RADIOISOTOPES CONSIDERED

At project commencement, AECB provided a list of all licensed radioisotopes utilized in the Hamilton-Burlington area. This total of 72 radioisotopes included a number which do not result in significant exposure to humans from a municipal wastes perspective:

- radiotherapy doses are not considered directly in the dose calculations. Excretion of medical radioisotopes into the municipal sewage treatment system is considered as a source;
- the terms of reference indicate the study is to assume that AECB license requirements are met by licensees. Any radioisotope which licenses stipulate must be sent to AECL for storage are thus not considered, with the exception that sensitivity analysis was conducted to estimate the impact of accidental disposal of such materials into the municipal waste systems; and
- reactor and accelerator source radioisotopes were not considered since these wastes must go to AECL for management.

Under the above assumptions a number of radioisotopes could be eliminated from the study list to make it a more manageable and meaningful list. An assessment was then made of radioisotope uses in the Hamilton/Burlington area and which had any potential for being disposed into municipal waste management systems. Other critiera used in assembling this list included:

- half-lives in general should exceed two days for radioisotopes to be dose-significant due to waste management pathway transport time; exceptions were made if other criteria indicated the isotopes had potential environmental consequences;
- only radioisotope users were considered as sources suppliers were assumed to send all their radioisotopes to users prior to any disposal occurring; and
- if quantities used were too small to be easily measureable, or in quantities that, when coupled with pathway and radiotoxicity data, were biologically insigificant, these were excluded from the study.

Based on these criteria, a list of 22 radioisotopes was assembled. The criteria for selection included:

- P-33, Zn-65 and Ni-63 were included due to reported research uses at the Canada Centre for Inland Waters (CCIW) in Burlington;
- radioisotopes included due to significant medical uses which result in disposal into municipal waste streams include tritium, C-14, Cr-51, P-33 (P-32), S-35, Tc-99m, I-125 and I-131;
- literature on sewage treatment plant sludges (Durham and Joshi, 1979) indicates presence of Cr-51 and I-131;
- two radioisotopes were included due to widespread use in instruments, Am-241 and Ni-63; and
- the longer-lived uranium and thorium decay series were included since some have been reported in sewage sludges and many are used by researchers at the Canada Centre for Inland Waters: Po-208, Ra-226, Th-228, Th-230 and Th-232.

Following discussions with AECB and further research on radioisotope uses and potential disposal, the list was further modified as follows:

- the uranium decay series was excluded;
- P-32 and P-33 were considered as one radioisotope (P-33); and
- Tl-201, Ga-67, Se-75 and Co-57 were added.

This resulted in a final study list of 16 radioisotopes as follows:

- tritium (H-3)
- carbon-14 (C-14)
- phosphorus-32 (P-32) and phosphorus-33 (P-33)
- sulphur-35 (S-35)
- chromium-51 (Cr-51)
- cobalt-57 (Co-57)
- nickel-63 (Ni-63)
- zinc-65 (Zn-65)
- gallium-67 (Ga-67)

- selenium-75 (Se-75)
- technetium-99m (Tc-99m)
- iodine-125 (I-125)
- iodine-131 (I-131)
- thallium-201 (Tl-201)
- polonium-210
- americium-241 (Am-241)

Appendix C gives a detailed review of the uses of various radioisotopes and the criteria used for inclusion in this study.

SECTION 4

SOURCES OF RADIOISOTOPE WASTES

4.0 SOURCES OF RADIOISOTOPE WASTES

4.1 General

The three main wastes of potential concern to the project are:

- liquid wastes disposed to the sewer,
- solid wastes disposed to landfill or incinerated, and
- liquid or solid wastes returned to Chalk River.

The three main sources are:

- household,
- institutional (university and hospital), and
- commercial/industrial/governmental

Wastes considered in this assessment are those disposed of through municipal systems; hence industrial wastes disposed to their own or specialized industrial landfills are neglected. Wastes (liquid or solid) returned to Chalk River for storage are also not considered.

Our analysis of the AECB licences in the Hamilton-Burlington area and contact with several licencees indicate that the main source of wastes of concern to this project are derived from hospitals and universities. Liquid wastes represent the means for disposal of most of these radioisotopes.

In hospitals, all in vivo and most in vitro applications use radioisotopes in liquid form. In vivo uses require solution for injection into the body. Organic (in vitro) studies also require solution form. Radioisotopes for in vivo uses are generated in the reactor, in radiopharmacy, or leftover liquid solutions. From the laboratory, liquid wastes go down the sink if their activity is below the amounts stated in the license issued to users by the AECB, except those which are returned to Chalk River. The only potentially contaminated solid wastes from hospitals would be laboratory tissues, lab coats, pipettes, etc. These are considered as part of the sensitivity analysis.

The largest portion of solid wastes from universities and hospitals are sealed sources and reactor components. Under definitions of this project, sealed sources are assumed to be returned to Chalk River, with two exceptions - Am-241 in smoke detectors and Ni-63 in electron capture detectors in gas chromatographs (GC). Smoke detectors are exempt from AECB licensing and are routinely disposed in regular garbage. The sealed source in gas chromatographs should be returned to Chalk River. Recently at McMaster, one GC was returned to the radioisotope authorities because a technician noted the label on the GC. But because many do not appear to have such labels visible, the chance of all GC's being disposed of properly has been judged to be small. Hence, it is assumed that one GC per year is disposed to landfill.

Radioisotopes are used for analytical standards in water samples and sediment and soil samples. If these quantities are below specified limits, they can be disposed to sewers or to solid waste.

With respect to other solid waste sources, it is plausible that some spillage during use in solution will occur in the laboratory. Towels, disposable tissues, etc. used for cleanup and laboratory gloves in contact with spills should be disposed to specially marked garbage cans whose contents are sent to Chalk River. Under the assumption that all of this solid waste is not sent to Chalk River, a separate analysis is made based on the assumption that 10% of this waste is sent to the solid waste collection system.

From the research reactor at McMaster University, all solid wastes (e.g., Mo-99) are returned to Chalk River; hence they are not considered in this project.

The radioisotope sources and releases in Hamilton-Burlington are expected to be typical of medium-sized municipalities in Canada. Hamilton is somewhat unique in that all radioisotopes used in the hospitals are either generated by the reactor or obtained by the McMaster Departments of Health Physics or of Radiopharmacy and then supplied to the hospitals. The University is also responsible for collecting all wastes and then shipping them to Chalk River. In addition, the University collects and ships sealed sources and other radioisotopes from local industry (e.g., Stelco, Dofasco, etc.) to Chalk River.

4.2 Households

The two main household sources of radioisotopes identified are Am-241 in smoke detectors, and sewer inputs of urine, and feces from humans who have been injected with a radioisotope in a hospital. This latter source is considered as a part of institutional (university and hospital) sources.

The Am-241 source in smoke detectors is contained in a gold matrix sealed between a silver backing and a thin gold alloy cover. Because the integrity of smoke detectors in the solid waste system cannot be guaranteed, some release of Am-241 is assumed. Based upon our analysis of their life-time in households (see Appendix D) and the analysis of others (Belanger et al., 1979), we have adopted a loading to solid waste handling of 0.64 GBq/yr (see Table 4.1).

4.3 Institutional (University and Hospitals)

Liquid wastes are the main source of radioisotopes from hospitals and universities. All solid wastes of significance are sent to Chalk River for storage, with the exception of cleaning towels etc., which may be accidently disposed to the municipal waste collection system.

The following radioisotopes have been identified as discharged in significant quantities to the sewer system: C-14; Co-57; Cr-51; Ga-67; H-3; I-125; I-131; P-32; S-35; Tc-99m; and Tl-201. These are used for in vivo and/or in vitro medical purposes. The licenced users are given in Appendix C. Special comments on their uses and the chemistry of these radioisotopes in the body or in laboratory studies are given in Appendix E. The quantities disposed to the sanitary sewer system are given in Table 4.2. It is assumed that all of these radioisotopes are disposed to the Hamilton Wastewater Treatment Plant. Only radioisotopes supplied to Joseph Brant Hospital in Burlington would be misplaced by this assumption. The supply to Joseph Brant is small, justifying this assumption.

The only radioisotope of significance disposed to solid waste is Ni-63 in the election capture detector of gas chromotographs (GC). It is assumed that one GC per year is mishandled and disposed to the Hamilton solid waste collection system. It is assumed that this GC is disposed through SWARU to landfill.

TABLE 4.1: QUANTITIES OF RADIOISOTOPES IN SOLID WASTE AND THEIR PARTITIONING IN INCINERATORS AND LANDFILL

Radioisotope	Quantity to Solid Waste	Origin of Solid Waste	Form in Solid Waste	Solid Waste to Hamilton Landfill	Solid Waste to Incinerator to Landfill	Solid Waste to Apt. Incinerator to Landfill	Solid Waste to Burlington Landfill
Am-241	0.64 GBq/yr	Smoke detector	Alloy	.12 GBq/yr	.36 GBq/yr	.03 GBq/yr	.13 GBq/yr
C-14	None	-	-	-	-	-	-
Co-57	0.04 GBq/yr	Mossbauer Internal Stds in Lake Sediments	Ionic, Adsorbed?	0	0	0	.04 GBq/yr
Cr-51	None	-	-	-	-	-	-
Ga-67	None	-	-				-
H-3	None	-	-	-	-	-	-
I-125	None	-	-	-	-	-	-
I-131	None	-	-	-	-	-	-
Ni-63	.07 GBq/yr	Internal Stds in Lake Sediments	Ionic, Adsorbed?	0	0	0	.07 GBq/yr
	1 GBq/yr	1 Electron capture detector/yr	alloy	0	0.99 GBq/yr		
P-32	None	-	-	-	-	-	-
P-33	None	-	-	-	-	-	-
Po-210	1 GBq/yr	Antistatic devices	Fused in Glass Spheres	0	.99 GBq/yr	0	0
S-35	None	-	-	-	-	-	-
Se-75	None	-	-	-	-	-	-
Tc-99m	None	-	-	-	-	-	-
Tl-201	None	-	-	-	-	-	-
Zn-65	20×10^5 Bq	Analytical Internal Stds Lake Sediments	Ionic, Adsorbed to Sediment	0	0	0	20 M Bq/yr

TABLE 4.2: QUANTITIES OF RADIOISOTOPES IN WASTEWATER AND THEIR PARTITIONING IN WWTP, INCINERATOR AND LANDFILL

Radioisotope	Quantity to Sewer System	Origin of Liquid Waste	Chemical Form in Liquid Waste	Loss in Sewer System	Quantity to WWTP Discharge	Quantity to WWTP to Atmosphere	Quantity to WWTP Sludge	Sludge to Incinerator to Ash	Sludge to Incinerator to Atmos.
Am-241	None	-	-	-	-	-	-	-	-
C-14	0.5 G Bq 2 G Bq/yr	Univ and Hosp BAC-TEC Units stored for analytical chemistry	Organic-C (yeast)	Decay to CO_2	0.42 G Bq/yr	0	0.08 G Bq/yr	0	.02 G Bq/yr
Co-57	2000 Bq	Human Internal	Ionic	None	1,800 Bq/yr	0	200 Bq/yr	200 Bq/yr	0
Cr-51	3 G Bq	Human Internal*	Ionic	None	2.3 G Bq/yr	0	0.7 G Bq/yr	0.7 G Bq/yr	0
Ga-67	77 G Bq/yr	Human Tracer	Ionic	8 G Bq/yr	51 G Bq/yr	0	14 G Bq/yr	14 G Bq/yr	0
H-3	2 G Bq	Labelling Studies in Univ. & Hosp. experiments etc.	Org-H3 fairly stable	0	0.1 G Bq/yr	0.9 G Bq/yr**	0.24 G Bq/yr	0	0.24 G Bq/yr
I-125	28 G Bq/yr	Fibrogen I	Organic I	0	28 G Bq/yr	0	.005 G Bq/yr	5 k Bq/yr	1 M Bq/yr
I-131	8- G Bq/yr	Thyroid Treatment	Iodide	0	80 G Bq/yr	0	20 M Bq/yr	16 M Bq/yr	4 M Bq/yr
Ni-63	None	-	-	-	-	-	-	-	-
P-32	3 G Bq	Univ. and Hosp. Labelling Cmpds	Ionic	0	0.3 G Bq/yr	0	2.7 G Bq/yr	2.7 G Bq/yr	0
P-33	4×10^6 Bq***	Liquid Tracer	Assume it is input to L. Ont.	-	-	-	-	-	-
Po-210	None	-	-	-	-	-	-	-	-
S-35	1.5 G Bq	Purchased as Methionine	Organic-S (Reduced State)	0	1.3 G Bq/yr	0	0.18 G Bq/yr	0	0.18 G Bq/yr
Se-75	None	-	-	-	-	-	-	-	-
Tc-99m	21 T Bq/yr	Pertechnetate	Ionic	17 T Bq/yr	0.59 T Bq/yr	0	0.48 T Bq/yr	10-13 Bq/yr	0
Tl-201	58 G Bq/yr	Used for Heart studies	Ionic	6.1 G Bq/yr	49 G Bq/yr	0	52 M Bq/yr	0.57 M Bq/yr	0
Zn-65	None	-	-	-	-	-	-	-	-

* Used to label platelets.

** Includes burning of CH_4 gas

*** To Lake Ontario, not sewer system

All solid materials (tissues, paper towels, gloves) from institutions which are collected in radiological garbage cans are collected by McMaster and shipped to Chalk River. Because it is improbable that all such waste goes to Chalk River, a special set of calculations of radioisotope concentrations (see Appendix D) are made assuming that 10% of this material goes to the solid waste system. The quantity spilled and requiring cleanup is assumed to be 1% of the quantity disposed to the sewer system (see Table 4.2). This is based upon the argument that in vivo and in vitro uses of radioisotopes are customarily handled in 10 mL vials containing 10 mCi (0.4 GBq) and that one drop (0.1 ml) is spilled per vial. This results in 0.001 of the quantity disposed to sewer system being disposed to solid waste.

4.4 Commercial and Industrial

Commercial, industrial and governmental sources generate liquid and solid wastes. Liquid wastes of significance are C-14 (Table 4.2), which go to the Burlington sewage treatment plant. Solid waste sources are Co-57, Ni-63, and Zn-65 (see Table 4.1) used for analytical measurement in sediments and disposed to the Burlington landfill and Po-210 disposed as anti-static devices. The supplier of anti-static devices (located in London) requests that all used devices be returned to them for disposal. Because 10% are assumed not to be returned, an estimate of the amount disposed to landfill has been made (see Appendix D). This is not a large amount as it is contained in 36 devices disposed each year. Po-210 is encased in a 1 mm diameter glass sphere in these devices.

SECTION 5

RELEASE PATHWAYS AND PARTITIONING

5.0 RELEASE PATHWAYS AND PARTITIONING

5.1 Liquid Wastes

Liquid wastes travel, generally by gravity, through the sanitary sewer system to the wastewater treatment plant before discharge to a receiving water. Some surcharges of storm water from combined sewers in downtown areas of Hamilton add to the hydraulic load to the plant. The Hamilton Waste Water Treatment Plant (WWTP or STP for Sewage Treatment Plant) treats wastes from the City of Hamilton, including McMaster University, Chedoke, Henderson, St. Joseph's and General Hospitals, as well as Ancaster and Stoney Creek. It discharges to Hamilton Harbour.

The Dundas STP treats waste from Dundas; no waste radioisotope sources of significance have been identified in Dundas, allowing it to be ignored.

The Burlington Skyway WWTP treats wastewater from part of Burlington (Joseph Brant Hospital and chemical laboratories) and also discharges to Hamilton Harbour.

Radioisotope loss from the sewer system can occur because of volatilization to the "sewer's" atmosphere, adsorption to the sewer pipes, etc., and radioactive decay. The volatile radioisotope tritium does not decay appreciably in the sewer system (Table 4.2) because of its long half-life. Organic carbon containing C-14 will decompose in the sewer system; it is assumed that this converts organic C-14 to aqueous inorganic C-14 (dissolved CO_2; bicarbonate; carbonate) resulting in no sewer system loss to the atmosphere. The extent of radioactive decay depends on the half-life relative to the time spent in the sewer system. For the assumed average travel time in Hamilton sewers of 12 hr, only Tc-99m Ga-67, and Th-201 undergo significant decay (see Table 4.2).

The points of discharge from the different hospitals and the university to the sewer systems are shown in Figure 5.1. They are generally a sufficient distance from the WWTP that the adoption of a uniform detention (transit) time in the sewer system is justified.

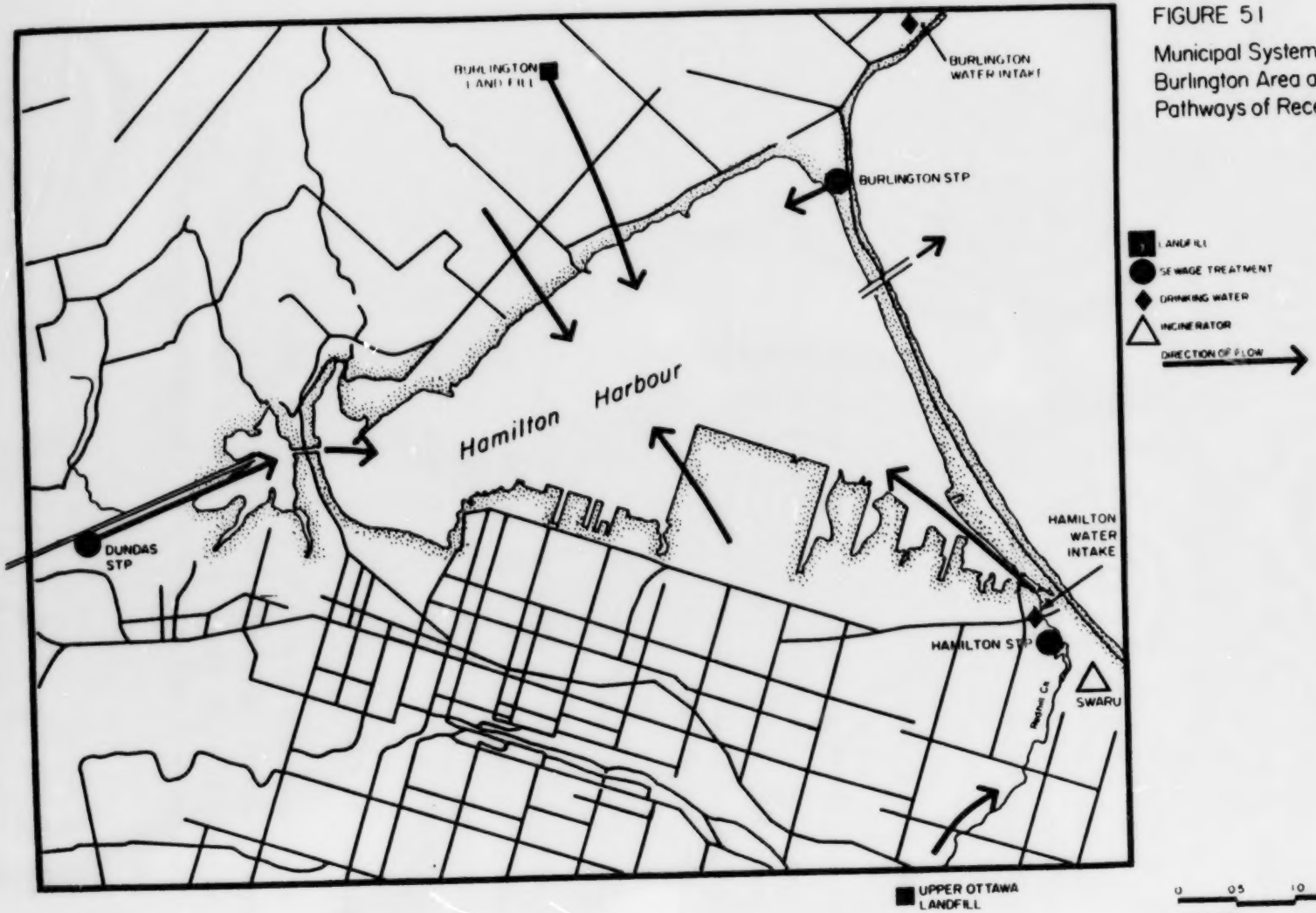


FIGURE 51

Municipal Systems of Hamilton-Burlington Area and Hydrological Pathways of Receiving Waters

Hamilton Wastewater Treatment Plant (WWTP)

A flowsheet schematic of a generic WWTP is given in Figure 5.2. The main function of grit removal and primary clarification is to remove inorganic particles (sands and gravels); some organic particles and metals are also removed. Secondary aeration tanks in the presence of oxygen convert much of the soluble organic wastes to particulate forms through bacterial growth and adsorption, while the secondary clarifiers permit the organic solids to settle.

The settled sludge, containing large numbers of bacteria, is returned to the head of the aeration tank where it is mixed with the incoming sewage. Part of the return sludge is transported to anaerobic digestors. Digestors convert the sludge to gas, dissolved organics (supernatant) and to a more dense sludge. This sludge is burned in the WWTP incinerator. Residue from the incinerator is mixed with gravel and transported to the city for use in road building material.

The effluent from the plant contains residual soluble organics and metals, and 'light' particles which did not settle in the secondary clarifier. Chlorination of the effluent is generally practiced during the summer to destroy pathogenic bacteria. The effluent flows into the estuary of Red Hill Creek and then into the Windemere Basin, a shallow arm of Hamilton Harbour (see Figure 5.1).

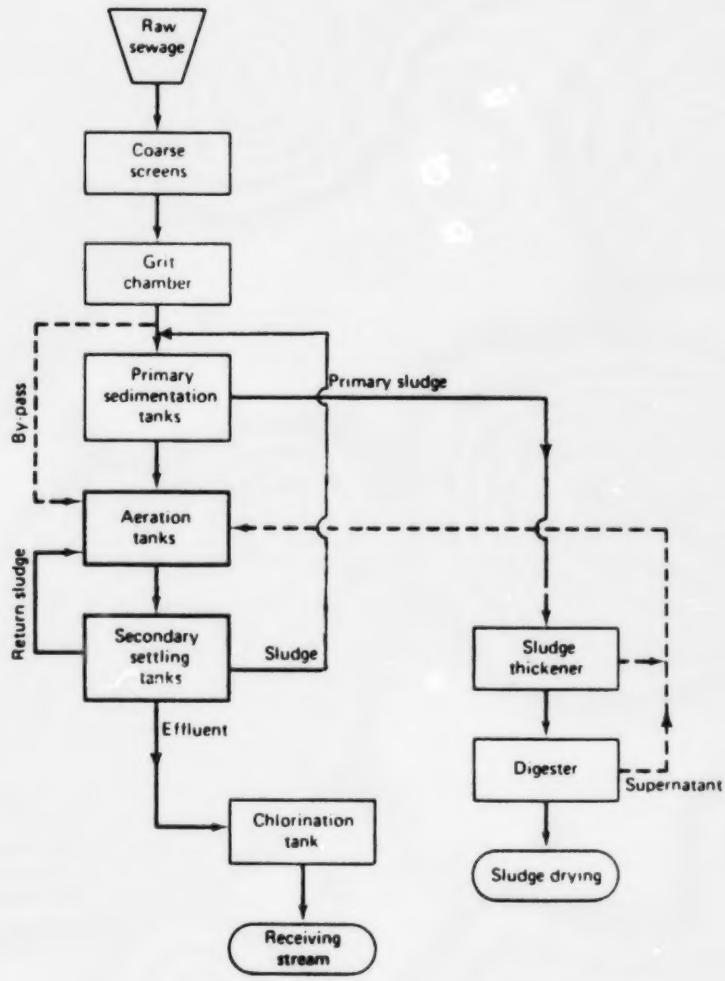
Burlington Wastewater Treatment Plant

The flowsheet for the Burlington WWTP is similar to that for Hamilton (see Figure 5.2). It differs only in the method of sludge handling. The Burlington plant does not have an incinerator, although one is proposed. Rather, sludge from the incinerator is transported to the Burlington landfill, or is spread as fertilizer on agricultural land.

Radioisotope Partitioning in WWTP

For purposes of this project, the hydraulic detention time, sludge detention time (sludge age) and other parameters for Hamilton and Burlington are treated as similar with the exception of the method of digestor sludge handling. Hamilton digestor sludge is incinerated and deposited in road bed material while Burlington sludge is landfilled at the Burlington landfill.

FIGURE 5.2: WASTEWATER TREATMENT PLANT FLOW DIAGRAM



The chemical and physical partitioning of radioisotopes through the WWTP are given in Table 4.2. The detailed assumptions and calculations are given in Appendix D. These are summarized as follows. All radioisotopes are discharged from human body in the urine, or feces. Many radioisotopes injected into the body are in an organic (chelated) form. They can be discharged in the feces and remain in the organic form, but if discharged in the urine, they will normally be in an ionic form, in order to pass through the kidney. These points are used to estimate the chemical speciation of the radionuclides in sewage.

In the WWTP, ionic forms are taken up by bacteria to varying degrees and/or adsorbed. Organic forms are converted to inorganic forms by decomposition processes. Some (e.g., P-32) may be sorbed or chemically precipitated by alum or iron salts. If the radioisotopes are in a particulate form in the aeration tank, they will settle with the sludge and be partitioned to the digestor with the sludge whereas nonsettling particulates and soluble forms will be carried out of the WWTP with the effluent.

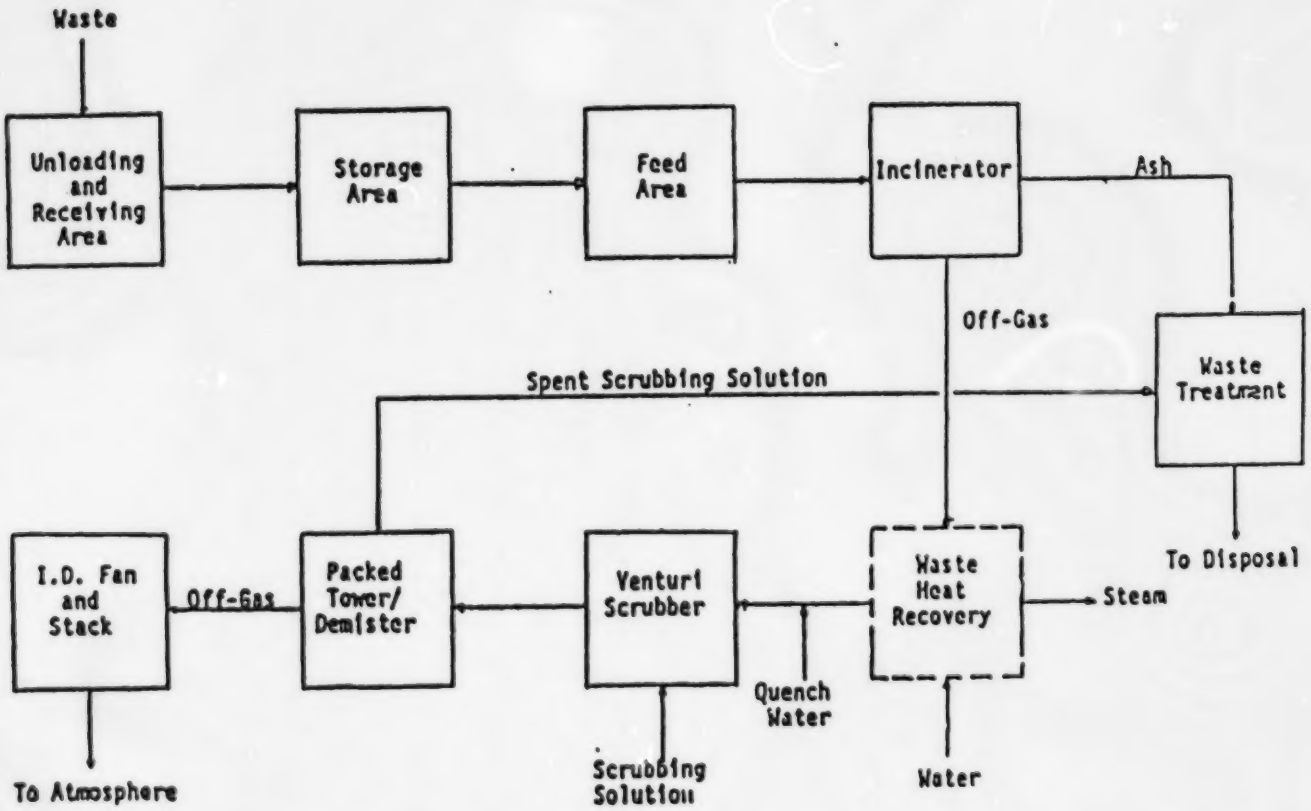
Actual data of metal partitioning (e.g., Cr) are used where available to estimate partitioning in the plant. Where such data are not available, the chemical similarity of radioisotopes to other metals (e.g., Co to Ni, Ga-67 to Al; Tl-201 to K) and the partitioning characteristics of these metals are used to estimate partitioning. For C-14 and tritium, the partitioning of biochemical oxygen demand (carbon as bacteria substrate) is used as the surrogate. Of all the isotopes, the partitioning used for Tc-99m is probably one of the more tenuous.

Radioisotope Partitioning in Incinerator

A flow schematic of an incinerator is described below for solid waste disposal (Figure 5.3). Because the WWTP incinerator operates under similar principals, a schematic is not given here.

The majority of radioisotopes pass through the incinerator without significant partitioning to the atmosphere. Only for C-14, S-35 and tritium are most of the radioisotope partitioned to the atmosphere. A minor quantity of I-125 and I-131 is partitioned to the atmosphere. For other radioisotopes, it is assumed that 1% of the ash remaining after combustion escpes from the incinerator to the atmosphere.

FIGURE 5.3: TYPICAL INCINERATOR BLOCK FLOW DIAGRAM



Radioisotope Partitioning in Landfill

Radioisotope partitioning assumptions in the landfill from liquid-derived, solid waste are described below (Section 5.2).

Human Exposure to Liquid Waste

The following points in the liquid waste disposal system have been identified as critical points for human exposure:

- activated sludge tank maintenance person ('aeration worker')
- sludge room worker
- solid waste (ash) trucker
- incinerator ash loader

Details of their exposure geometry and other aspects of these locations and workers are given in Sections 10 and 11.

The radioisotope concentrations affecting workers at these points are given in Table 5.1. These concentrations are derived from the partitioning through the treatment system (Table 4.2). The detailed calculations are given in Appendix D.

Population Exposure to Radioisotopes Derived from Liquid Waste

The collective population exposure to radioisotopes of concern to this study is derived mainly from radioisotopes in liquid waste. There are two main human exposure pathways: the water supply system and the atmosphere. The methods for calculating the hydrologic pathway effect upon WWTP discharges are given in Section 10.1. The detailed calculations of quantity for the atmospheric discharges are given in Appendix D.

5.2 Solid Waste

Solid waste is collected from the household or institution and transported to a transfer station. Here the refuse is loaded into a larger truck with a higher degree of compaction within the truck and carried either to landfill or to the incinerator. Residue from the

TABLE 5.1: CONCENTRATIONS OF RADIOISOTOPES AT VARIOUS POINTS IN THE MUNICIPAL WASTE DISPOSAL SYSTEMS

	Hamilton Liquid Waste Pathways			Burlington Liquid Waste Pathways		Solid Waste Pathways							
Radio-isotope	Aeration Tanks (Bq/cc)	STP Ash (Bq/cc)	STP Sludge (Bq/cc)	Aeration Tanks (Bq/cc)	STP Sludge (Bq/cc)	Garbage Hamilton (Bq/cc)	Incinerator Ash (Bq/cc)	Landfill Hamilton (Bq/cc)	Garbage Burlington (Bq/cc)	Landfill Burlington (Bq/cc)	Release to Hamilton Harbour (Bq/a)	Release to Atmosphere (Bq/s)	City Drinking Water (Bq/L)
H-3	1.00E-5	0	3.33E-3	0	0	0	0	0	0	0	1.00E8	0	1.26E-5
C-14	4.46E-6	0	2.67E-4	1.75E-5	1.59E-3	0	0	0	0	0	1.40E9	0	4.45E-4
P-32	2.68E-5	1.89E-1	3.75E-2	0	0	0	0	0	0	0	3.00E8	0	2.00E-5
P-33	0	0	0	0	0	0	0	0	0	0	0	0	6.13E-11
S-35	1.34E-5	1.49E-2	2.50E-3	0	0	0	0	0	0	0	1.32E9	0	3.07E-4
Cr-51	2.68E-5	5.12E-2	9.58E-3	0	0	0	0	0	0	0	2.31E9	0	3.09E-5
Co-57	1.79E-11	1.65E-8	2.78E-9	1.15E-11	1.74E-10	0	0	0	5.56E-5	1.93E-4	2.96E3	0	3.86E-10
Ni-63	0	0	0	1.02E-8	6.35E-7	2.78E-4	3.67E-3	1.65E-3	9.72E-5	3.89E-4	1.40E6	3.17E-1	2.23E-7
Zn-65	0	0	0	6.31E-11	2.99E-9	0	0	0	2.78E-4	1.09E-4	5.66E3	0	2.59E-10
Ga-67	5.84E-4	5.92E-1	1.92E-1	0	0	0	0	0	0	0	5.16E10	0	1.47E-4
Se-75	0	0	0	0	0	0	0	0	0	0	0	0	0
Tc-99m	5.24E-3	1.67E-24	5.51E-24	0	0	0	0	0	0	0	5.87E11	0	1.32E-4
I-125	2.50E-4	5.78E-4	9.72E-5	0	0	0	0	0	0	0	2.80E10	0	8.91E-3
I-131	7.14E-4	1.25E-3	2.78E-4	0	0	0	0	0	0	0	8.00E10	0	2.55E-2
Tl-201	4.37E-4	2.36E-5	7.94E-1	0	0	0	0	0	0	0	4.89E10	0	1.30E-3
Po-210	0	0	0	3.64E-15	5.11E-12	2.22E-4	2.20E-3	7.28E-4	2.78E-4	6.11E-4	3.65	1.90E-1	9.06E-13
Am-241	0	0	0	1.48E-15	1.98E-12	1.33E-4	1.31E-3	8.37E-4	1.87E-4	7.47E-4	2.24E-2	1.14E-1	6.91E-16

incinerator is landfilled. All of Burlington's garbage goes directly to the landfill, while it is estimated that 75% of Hamilton's garbage goes to the incinerator with the remainder going directly to the landfill. The 75% estimate is based upon the capacity of SWARU and its frequent maintenance problems. Generally, in Hamilton, residential garbage collected by the municipality goes to the incinerator while industrial and institutional wastes are collected by private haulers and go to the landfill.

Am-241 (smoke detectors) and Po-210 (anti-static devices) are collected in both cities for disposal at both landfills. Both are also assumed to pass through Hamilton's incinerator. Ni-63 from a gas chromatograph is disposed through the incinerator to Hamilton's landfill. Co-57, Ni-63 and Zn-65 are disposed to Burlington's landfill, originating only from chemical laboratories in Burlington.

These are the only radioisotopes identified as being possibly present in solid waste; all other radioisotopes used in the Hamilton/Burlington area are supposed to be returned to Chalk River. Some of the radionuclides used in liquid forms for in vivo or in vitro uses may be spilled in the laboratory. All towels etc., used to clean up such spillage are supposed to be collected and returned to Chalk River; however, it is reasonable to assume that some may not be. To assess the possible dose from solid waste containing laboratory spillage of liquid-form radioisotopes (Table 5.2), it is assumed that 0.1% (see Section 4.3) of these radioisotopes are disposed to Hamilton's solid waste system. These sources of radioisotopes are calculated separately from other nuclides disposed as solid waste (Am-241, Po-210, Co-57, Ni-63, Zn-65).

Incineration

A flowsheet schematic of the operation of SWARU is given in Figure 5.4. Solid waste is dumped onto a holding area from which it is conveyed to the furnace. Residue from the furnace is trucked for final disposal (to landfill for SWARU; to road bed materials at the WWTP). Dust and gases from the furnace rise to the atmosphere through the incinerator stack. Electrostatic precipitators remove most of the dust. In some incinerators, wet scrubbers remove such gases as SO_2; neither SWARU nor the WWTP incinerator have scrubbers. Here, we assume that 1% of the total ash residue is emitted to the atmosphere.

TABLE 5.2: CONCENTRATIONS OF RADIOISOTOPES IN SOLID WASTE DISPOSAL SYSTEM DUE TO SPILLAGE IN THE LABORATORY

Radio-isotopes	Concentration in Garbage (Bq/cc)	Concentration in Residue from SWARU (Bq/cc)	Concentration in Hamilton Landfill (Bq/cc)
Am-241	-	-	-
C-14	6.9E-7	0.0	1.0E-6
Co-57	5.6E-12	5.5E-11	2.9E-11
Cr-51	8.3E-7	8.3E-6	5.5E-7
Ga-67	1.7E-5	1.7E-4	1.3E-6
H-3	5.6E-7	0	8.3E-7
I-125	7.8E-6	7.7E-5	1.1E-5
I-131	2.1E-5	2.1E-4	4.2E-6
Ni-63	-	-	-
P-32	8.3E-7	8.3E-6	2.8E-7
P-33	-	-	-
Po-210	-	-	-
S-35	4.2E-7	4.1E-6	8.4E-7
Se-75	-	-	-
Tc-99m	1.5E-3	1.4E-2	8.7E-6
Tl-201	1.5E-5	1.4E-4	1.0E-6
Zn-65	-	-	-

Landfill

Solid waste and incinerator residue are trucked to and dumped into the landfill in specific lifts. A bulldozer or similar vehicle is used to level the waste and compact it. At the conclusion of a day's operation, clean fill is laid over the landfill. For the purposes of this project, it is assumed that the deposited refuse is homogeneously mixed with clean fill.

Rainwater will mix with and/or infiltrate the solid waste during the period that the site is being filled. Runoff can leave the landfill via surface and groundwater pathways. In older landfills, surface runoff may simply enter the watershed. In more recent landfills, both surface runoff and infiltrating rainwater are collected and returned to a treatment system.

In 1980, Hamilton closed out its old landfill site (Upper Ottawa Street) and opened a new site (Glanbrook). The new Glanbrook site is outside the drainage basin of the study area. Burlington continues to use its landfill. At the current time, due to filling up of the landfill site and the time required to obtain permits for a new site, some 400 t/d of garbage are being trucked to an incinerator in New York State. Since this is a temporary measure, it is assumed all solid wastes still go to the Burlington site. Groundwater drainage from Upper Ottawa flows into Red Hill Creek while the Burlington landfill could possibly drain into shallow groundwater and into sedimentary rock structures which drain to Hamilton Harbour. This latter is a hypothesis currently undergoing extensive research. Due to lengthy retention of leachates in shales and clays underlying the site, recent environmental studies conclude the input to Hamilton Harbour is not significant (Hydrology Consultants, 1985). For this study, it is assumed that Hamilton's landfill is still located at Upper Ottawa Street, at a site 150 m from Red Hill Creek, and that all infiltrating water flows via groundwater to Red Hill Creek. It is assumed that Burlington's landfill is underlaid with tile drainage such that all seepage is returned to the Burlington WWTP for treatment. This is currently partially true with further installation planned. Ongoing hydrogeological studies have yet to resolve how much is not collected and where it ends up.

Solid Waste Partitioning

The partitioning of radioisotopes disposed in solid waste, has been calculated in Appendix D. These calculations are summarized in Table 4.1. The quantities of radioisotopes normally disposed to sewer systems but assumed to be spilled in the laboratory and their solid waste partitioning are also calculated in Appendix D. These quantities are used to assess concentrations at various critical points in the solid waste handling system (see Table 5.2).

Human Exposure to Solid Waste

The following points have been identified as critical points for human exposure to solid waste disposal:

- garbage handler in the collection system
- incineration sorter
- loader and truck driver for incinerator ash
- landfill bulldozer operator

Details of the geometry etc., of these points are described in Appendix B. The influence of this geometry for the description of factors affecting external dose calculations are given in Section 11.0.

Radioisotope activities in solid waste, incineration residue, and the landfill are given in Table 5.1. The activities to which the garbage handler and the incinerator sorter are exposed are essentially the same. The radioisotope activity in incinerator residue is mainly a function of the 90% reduction in volume of solid waste by incineration.

Radioisotope activities for the special set of calculations due to laboratory spillage are given in Table 5.2 for the same points in the solid waste system. The activity affecting the incinerator sorter is the same as the garbage worker. The residue activity reflects the 90% reduction in volume; the content of C-14, S-35 and tritium is mainly controlled by their partitioning to the atmosphere in the incinerator. The landfill radioisotope activity is the annual average activity, and reflects the effect of radioisotope decay. Decay is most important for Tc-99m, but also quite important for Ga-67 and Tl-201.

Decay in the landfill is also important, to some degree, for all other radioisotopes except C-14, Co-57, H-3, and S-35. This point can be assessed by reference to the flux calculations in the appendix.

SECTION 6.0

OVERVIEW OF METHODOLOGY

6.0 OVERVIEW OF METHODOLOGY

Earlier sections of this report have identified:

(1) which particular radioisotopes are to be considered in this assessment based upon their quantity of use, half-lives and potential radioactivity (Section 3):

(2) where these particular radioisotopes originate in the community and the quantities that are disposed of in municipal waste (Section 4); and

(3) the particular waste treatment pathway followed by each radioisotope and its fate in passing through a particular waste handling and treatment system (Section 5).

In order to derive the particular doses resulting from the municipal disposal of these radioisotopes, it is necessary to carry out two additional steps. The first is to define which waste handling workers are likely to be exposed to the highest dose derived from municipal disposal of radioactive waste. These are defined in Sections 7 and 8. The second is to define a series of environmental transport pathways that will allow the calculation of a collective dose for the total population of the study area (Hamilton-Burlington), as well as a dose for the critical group in the general population identified as inhabiting the area where the incidental exposure is expected to be greatest. This model development and dose calculations are presented in Sections 9 to 11.

6.1 The Critical Group Concept

A major objective of the study is to determine the dose to maximally exposed individuals. In principle, this group can be identified by conducting detailed habit and diet surveys. This is a costly and time-consuming process and is not always practical or justifiable. In this study, conservative habit and diet assumptions are made in calculating doses to the group of maximally exposed individuals, or critical group. Although conservative assumptions have been made, one cannot state with one hundred percent certainty that there will not be some individuals whose habit and diet are so extreme that their doses exceed that calculated for the critical group, even though the probability of this is vanishingly small.

FIGURE 6.1: SCHEMATIC OF TRANSFER MODEL FOR HAMILTON BURLINGTON INCINERATION SYSTEMS

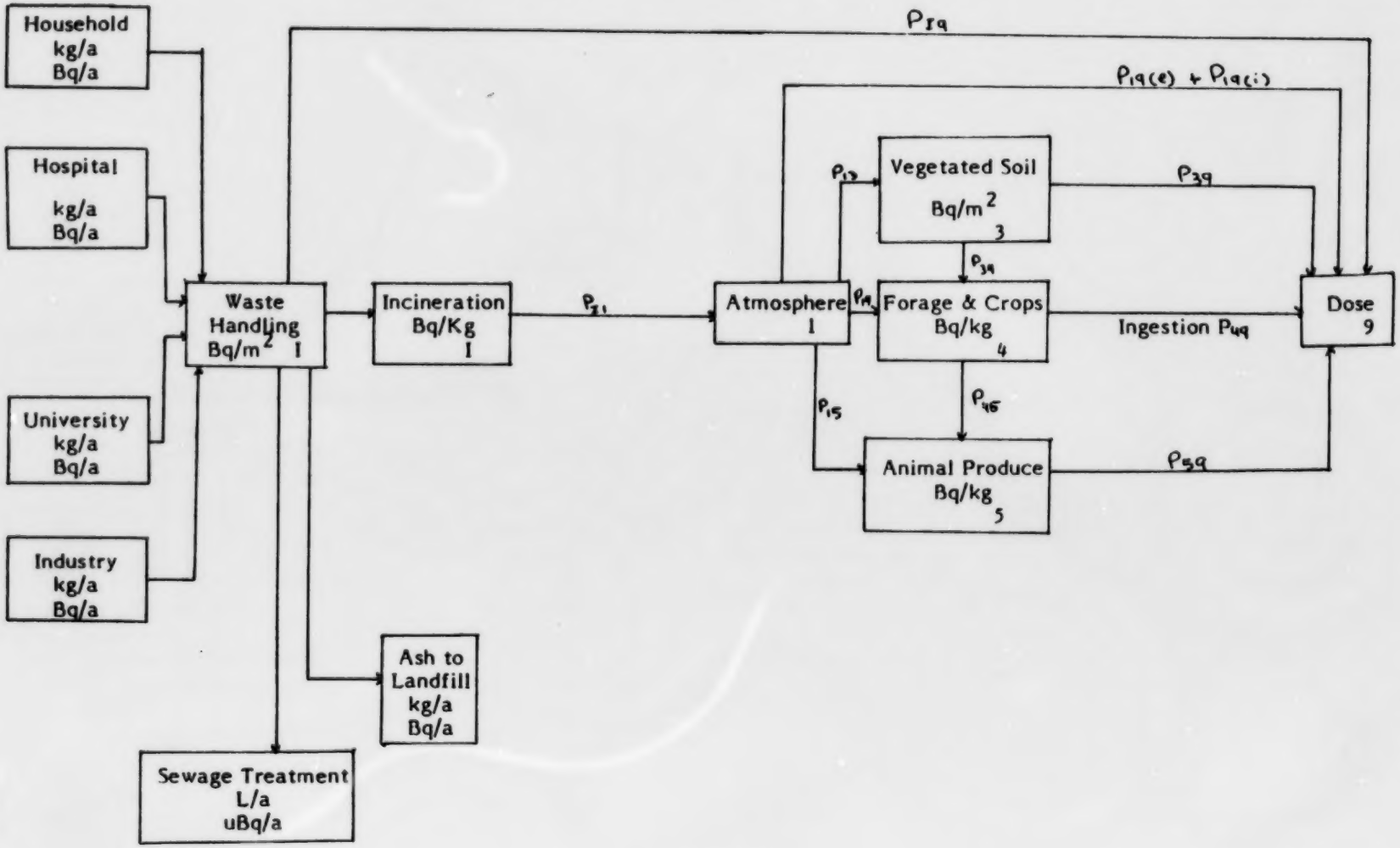


FIGURE 6.2: SCHEMATIC OF TRANSFER MODEL FOR HAMILTON BURLINGTON LANDFILL SITES

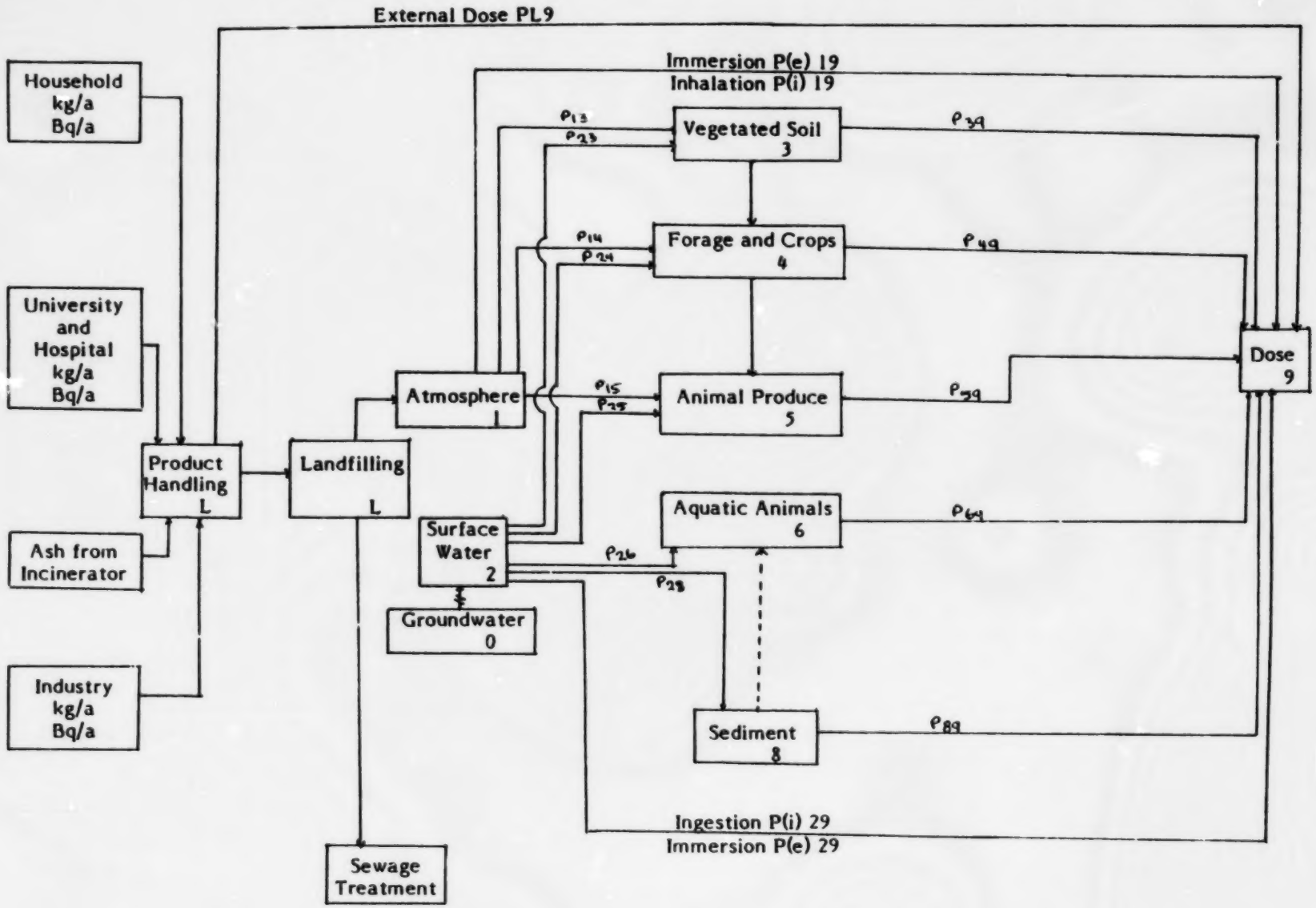
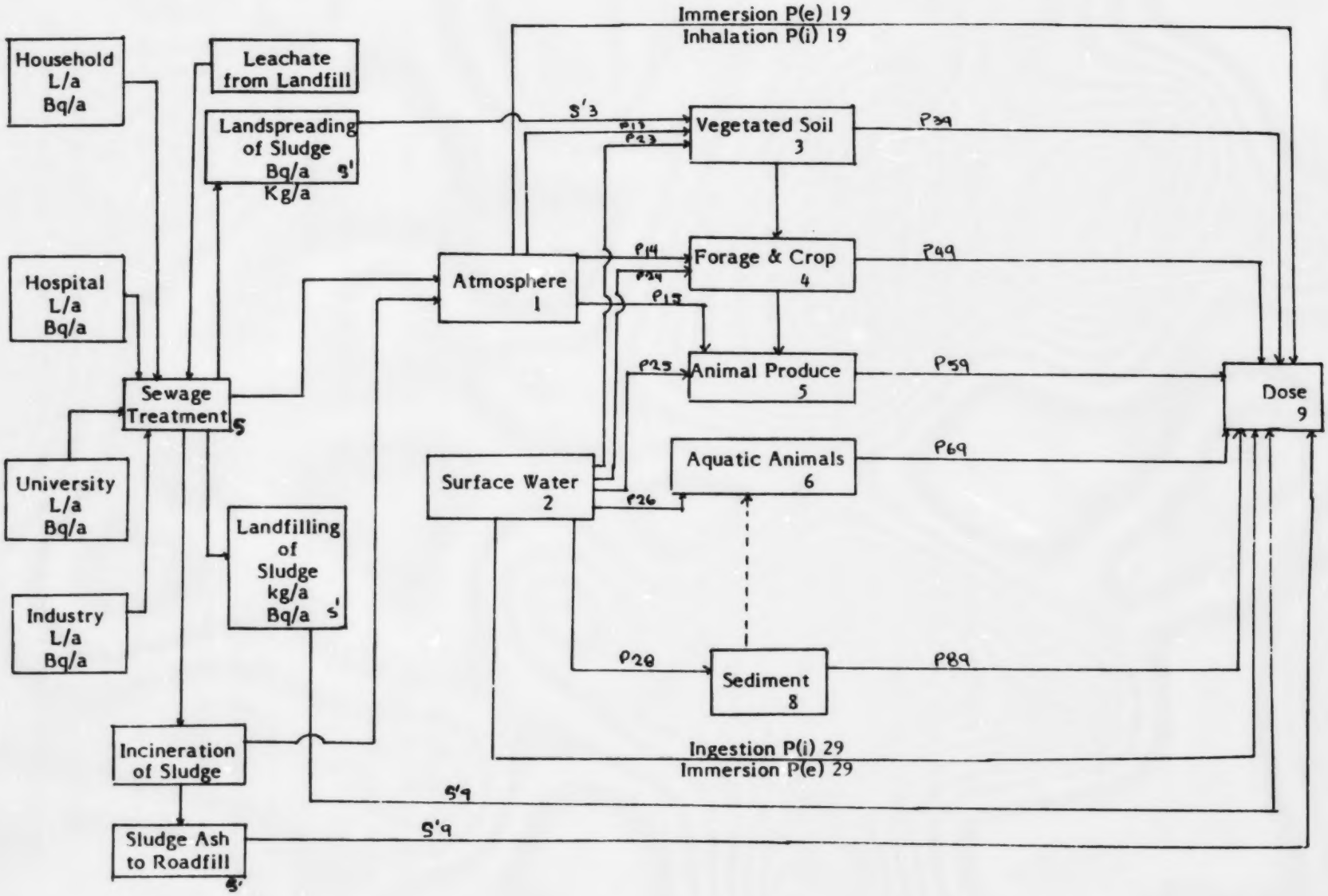


FIGURE 6.3: SEWAGE TREATMENT PLANT



For occupational workers in waste handling and treatment facilities, doses are calculated for various work groups based on their job duties. From these calculations, the maximally exposed group, or critical group, is identified.

6.2 Environmental Transfer Model

Environmental transfer models developed for the Hamilton-Burlington area for radioisotopes originating from each of the three waste handling systems are shown in Figures 6.1-6.3. These transfer models are for sanitary sewage treatment, sanitary landfill and municipal refuse incineration, respectively. Each of these diagrams presents a complete transfer model with all possible generic pathways identified. The major pathways that have been used to calculate collective dose are highlighted. The complete transfer diagrams are provided to allow for extension of this methodology to other areas and waste management technologies if warranted. Each of the waste management systems is evaluated with respect to its contribution to both individual and collective dose. A brief overview of the environmental dispersion pathways evaluated in this particular application follows.

6.2.1 Waste Management Systems

Municipal Waste Incineration: As discussed in Section 5.2, the only significant source of municipal waste received at the SWARU incineration facility in Hamilton is from residential garbage. The only significant source of incidental radioactive waste in residential garbage is Americium-241 found in certain types of ionization smoke detectors. In other Canadian cities, other sources may be sent to incineration. Figure 6.1 shows in schematic form the possible pathways that a particular radioisotope may follow in terms of its dose contribution to members of the general public. The highest individual exposure will occur during the waste handling operation. This exposure route was discussed in Section 6.1. During the incineration of the municipal waste, over 99% of the Americium-241 partitions to ash and is transported to the landfill for burial (Belanger et al., 1979). This pathway is shown in Figure 6.2. The 1% of the activity that partitions to the atmosphere is dispersed over the surrounding community assuming a relatively uniform wind rose. Doses are calculated due to inhalation, cloud immersion and external exposure from americium deposited on area soils. Because of the very low bioconcentration factors for americium and because of the fact that food and animal

produce produced within the urban Hamilton-Burlington area are not a significant portion of total community food consumption, the agricultural pathways are not included in the dose calculations.

As specified in licence requirements, solid waste contaminated with radioactive waste originating from hospital or university use, is all placed in sealed drums and shipped to Chalk River for storage. Because of the potential for some of these radioisotopes to enter municipal waste management systems through accidental means, a sensitivity analysis addressing this question is presented in Appendix I. This sensitivity analysis assumes that 0.1% of the radioisotope solid wastes from the hospital and university are disposed of by being placed in the wrong container and thrown out with the municipal waste.

For the purposes of population dose calculation, the pathway for radioisotope transport from the municipal incinerator to the atmosphere is designated as waste streams.

Disposal to Landfilling: The Hamilton-Burlington area has two landfills which receive municipal garbage and one which receives ash from the SWARU incinerator. The only other source of incidental radioactive waste disposal to the landfills would be research waste from aquatic and chemical laboratories that is not sent to Chalk River for storage. As in the case of the incineration, an estimate of waste that may inadvertently enter the wrong waste stream has been made and included in the context of a sensitivity analysis (Appendix F). Figure 6.2 shows the solid waste entering the landfill and the major release pathways leading from the landfill. Landfill leachate from the Burlington landfill is collected into drainage systems and diverted to the sewage treatment plant. This leachate then partitions according to the pathways given in Figure 6.3 for the WWTP. For Hamilton, the leachate from the landfill partitions to groundwater.

With respect to exposure to off-site individuals, the exposure route considered involves the leaching to groundwater, (e.g., Hamilton landfill) and the eventual discharge to surface waters in which the radioisotopes may be available for uptake by fish or human intake in drinking water.

For the purpose of collective dose calculations, releases from the landfill occur via the Wastewater Treatment Plant (waste stream 2 - see below).

Wastewater Treatment: The final waste treatment pathway examined in this study is through the municipal wastewater treatment system. Inputs to the treatment system shown in Figure 6.3, are derived primarily from the hospital and university sector. This study has made the assumption that after correction for decay, all of the radioisotopes given to patients for medical reasons are discharged to the sanitary sewer system. Figure 6.3 implies all of this input is from hospitals as this is where the radiological accounting is carried out. The fact that elimination of residual radioisotopes may continue after patients return home is assumed to make no difference to the result. Inputs from laboratories (universities, industrial, government) are derived from dilute water soluble waste research radioisotopes that may be intentionally or inadvertently put 'down the drain'. The other source considered was the input of leachate from the landfill site containing radioisotopes that may have leached from household garbage and incineration ash.

Environmental dispersion pathways from the WWTP include atmospheric releases from the burning of sludge, the release of C-14 and H-3 in the sludge digester and the release of radioisotopes in aerosols from aeration tanks, as well as the release to surface water of the treated water. The atmospheric release pathway considers dose contribution arising from inhalation, and external exposure to both the plume and ground deposited material. The aquatic pathway considers exposure from both the consumption of fish and water.

For the purpose of collective dose calculations, the WWTP is designated as waste stream 2. Waste stream 2A refers to releases from stacks, while 2B refers to releases at ground level.

6.2.2 Environmental Transport and Dose

Radioactive materials released to the environment are dispersed and transported through various environmental pathways. For the purpose of collective dose calculations relevant to the general population, only those pathways that would lead to radiation exposure to humans are of interest. These exposure pathways are:

1. external exposure from:
   - o immersion in the airborne plume,
   - o contaminated ground;

2. inhalation; and
3. ingestion of aquatic foods.

Other potential pathways include immersion in contaminated water and ingestion of terrestrial foods (crops, livestock). For releases into urban environments, these other pathways are judged to be insignificant.

For occupational workers, exposure occurs through the external and inhalation pathways:

1. external exposure from:
   - immersion in the airborne plume,
   - exposure to gamma radiation from waste at the workplace;
2. inhalation, primarily of dust, aerosols and volatile radioisotopes in the working environment.

Specific exposure models are developed for the individual workers in Section 8.0.

Following the approach used in the CSA N288.1 Standard, a generalized radioactive material transport model has been developed, as shown in Figure 6.3. This approach facilitates systematic development of the environmental transport models, data presentation and future updates.

The quantity in each block or compartment i in Figure 6.3 is denoted by X_i. Definitions of X_i and units used are summarized in Table 6.1. Transfer from compartment i to compartment j is characterized by a transfer parameter P_{ij} such that the amount in compartment j arising from transfer from compartment i under steady-state conditions is $P_{ij} X_i$. Thus, the quantity represented by any compartment j is given by:

$$X_j = \sum_i P_{ij} X_i \qquad (6.1)$$

where the summation is over all compartments transferring into compartment j. If all the P_{ij}'s are known, the quantity in any compartment for a given release rate X_S may be calculated. For example, in the case of releases to the atmosphere:

$$X_1 = P_{S1} X_S(a)$$
$$X_3 = P_{13} X_1 = P_{S1} P_{13} X(a)$$

TABLE 6.1: UNITS FOR GENERALIZED TRANSFER COMPARTMENTS

Compartment		Units
S*	(Sources)	$Bq \cdot s^{-1}$
0*	(Groundwater)	$Bq \cdot L^{-1}$
1*	(Atmosphere)	$Bq \cdot m^{-3}$
2*	(Surface Water)	$Bq \cdot L^{-1}$
3*	(Vegetated Soil)	$Bq \cdot m^{-2}$
4	(Forage, Crops, Browse and Lichen)	$Bq \cdot kg^{-1}$
5	(Animal Produce)	$Bq \cdot kg^{-1}$
6*	(Aquatic Animals)	$Bq \cdot kg^{-1}$
7	(Aquatic Plants)	$Bq \cdot kg^{-1}$
8	(Sediment)	$Bq \cdot kg^{-1}$
9*	(Dose)	$Sv \cdot a^{-1}$

Note: Replace Bq with ug in the case of U-NAT.

* Compartments considered in this study.

TABLE 6.2: UNITS FOR TRANSFER PARAMETERS

Transfer Parameter	Compartments	Units
P_{S1}*	Source to Atmosphere	$s \cdot m^{-3}$
$P(i)_{19}$*	Atmosphere to Dose (inhalation)	$Sv \cdot a^{-1} \cdot Bq^{-1} \cdot m^{3}$
$P(e)_{19}$*	Atmosphere to Dose (immersion)	$Sv \cdot a^{-1} \cdot Bq^{-1} \cdot m^{3}$
P_{13}*	Atmosphere to Vegetated Soil	m
P_{14}	Atmosphere to Forage, Crops, Browse + Lichen	$m^{3} \cdot kg^{-1}$
P_{15}	Atmosphere to Animal Produce	$m^{3} \cdot kg^{-1}$
P_{34}	Vegetated Soil to Forage, Crops + Browse	$m^{2} \cdot kg^{-1}$
P_{39}	Vegetated Soil to Dose	$Sv \cdot a^{-1} \cdot Bq^{-1} \cdot m^{2}$
P_{45}	Forage, Crops, Browse + Lichen to Animal Produce	$kg \cdot kg^{-1}$
P_{49}	Forage + Crops to Dose	$Sv \cdot a^{-1} \cdot Bq^{-1} \cdot kg$
P_{59}	Animal Produce to Dose	$Sv \cdot a^{-1} \cdot Bq^{-1} \cdot kg$
$P_{S2}(D)$*	Source to Drinking Water	$s \cdot L^{-1}$
$P_{S2}(H)$*	Source to Hamilton Harbour Water	$s \cdot L^{-1}$
P_{23}	Surface Water to Vegetated Soil	$L \cdot m^{-2}$
P_{24}	Surface Water to Crops	$L \cdot kg^{-1}$
P_{25}	Surface Water to Animal Produce	$L \cdot kg^{-1}$
P_{26}*	Surface Water to Aquatic Animals	$L \cdot kg^{-1}$
P_{27}	Surface Water to Aquatic Plants	$L \cdot kg^{-1}$
P_{28}	Surface Water to Sediment	$L \cdot kg^{-1}$
$P(i)_{29}$*	Surface Water to Dose (Ingestion)	$Sv \cdot a^{-1} \cdot Bq^{-1} \cdot L$
$P(e)_{29}$	Surface Water to Dose (Immersion)	$Sv \cdot a^{-1} \cdot Bq^{-1} \cdot L$
P_{69}*	Aquatic Animal to Dose	$Sv \cdot a^{-1} \cdot Bq^{-1} \cdot kg$
P_{79}	Aquatic Plant to Dose	$Sv \cdot a^{-1} \cdot Bq^{-1} \cdot kg$
P_{89}	Sediment to Dose	$Sv \cdot a^{-1} \cdot Bq^{-1} \cdot kg$
P_{S0}	Source to Groundwater	$s \cdot L^{-1}$
P_{02}*	Groundwater to Surface Water	(unitless)
P_{03}	Groundwater to Vegetated Soil	$L \cdot m^{-2}$

TABLE 6.2: UNITS FOR TRANSFER PARAMETERS

Transfer Parameter	Compartments	Units
P_{04}	Groundwater to Crops	$L \cdot kg^{-1}$
P_{05}	Groundwater to Animal Produce	$L \cdot kg^{-1}$
$P(i)_{09}$	Groundwater to Dose (Ingestion)	$Sv \cdot a^{-1} \cdot Bq^{-1} \cdot L$
P'_{09}	Groundwater to Dose (Inhalation)	$Sv \cdot a^{-1} \cdot Bq^{-1} \cdot L$
$P(e)_{09}$	Groundwater to Dose (Immersion)	$Sv \cdot a^{-1} \cdot Bq^{-1} \cdot L$

Note: Replace Bq with ug in the case of U-NAT.

* Transfer parameters considered in this study.

where $X_5(a)$ is the release rate to atmosphere. Similar expressions may be derived for releases to surface water $X_5(w)$ and to groundwater $X_5(g)$.

Transfer parameters indicated by dotted lines are conceptual pathways that are not explicitly calculated (Figure 6.3). Quantities of radioisotopes transported between atmosphere and surface water or groundwater are considered insignificant in comparison with the quantities discharged directly to these compartments by the wastewater treatment plant, incinerators and landfill. Transfers among the aquatic plants, aquatic animals and sediment compartments may be significant; however, concentrations in aquatic foods are calculated based on the ratio of the concentration in tissue to the concentration in surface water (bioconcentration factor). In using this simple bioaccumulation model, it should be recognized that tissue contaminant burdens result from bioaccumulation through the food chain and from sediments as well as directly from water.

The environmental transport models assume that steady-state conditions apply; however, in reality, non-steady state conditions may be expected to frequently occur. Nonetheless, for the long-term average, it is reasonable to assume that steady-state processes describe average conditions.

The calculation of dose is given herein for atmospheric, surface water and groundwater models of transmission.

Release to Atmosphere

For releases to the atmosphere via incinerator stacks, and sewage treatment tank digesters and aerators, the population is exposed through inhalation, immersion in the contaminated plume, and through gamma radiation from the ground stemming following the deposition of airborne radioisotopes.

Application of the environmental transfer model (Equation 6.1) to these pathways (Figure 4.2) gives the dose to humans $X_9(a)$ through atmospheric pathways as:

$$X_9(a) = P(e)_{19} X_1 + P(i)_{19} X_1 + P_{39} X_3 \qquad (6.2a)$$

from compartments 1 and 3. This expression may be expanded as follows:

$$X_9(a) = (P(e)_{19} + P(i)_{19})\, X_1 + P_{39}\, X_3 \qquad (6.2b)$$

$$= (P(e)_{19} + P(i)_{19})\, X_1 + (P_{39}\, P_{13}\, X_1) \qquad (6.2c)$$

Release to Surface Waters

Application of the environmental transfer model to these pathways gives the dose to humans for discharges to surface waters $X_9(w)$ as:

$$X_9(w) = (P(e)_{29} + P(i)_{29})\, X_2(D) + P_{69}\, X_6 \qquad (6.3a)$$

$$= (P(e)_{29} + P(i)_{29})\, X_2(D) + (P_{26}\, P_{69})\, X_2(H) \qquad (6.3b)$$

Calculating Doses for All Pathways

The calculation of doses for simplified pathways is accomplished by simply summing the doses from the atmospheric and aquatic pathways. For occupational critical groups, the total dose received is equal to the dose from the work place plus the dose received by residing in the general population. The highest dose will be received by workers who are also members of the critical group in the general population.

SECTION 7

CRITICAL GROUPS

7.0 CRITICAL GROUPS

7.1 Introduction

On-site field investigations using structured observational techniques (a sociological approach in which specific behavioural data are collected with minimal knowledge by or influence on the human subject (Whyte, 1977)) were used by project team members, in conjunction with interviews of Hamilton-Wentworth and Halton region personnel, to identify the most probable highly exposed individuals or occupational critical groups for this study. These are employees whose working habits, occupational environment, proximity to possible radioisotopes, exposure duration and exposure geometry would place them at greater risk to radiation exposure than other employees. The five components of the regions' waste management systems where this critical group can be found include:

- bulk handling of municipal waste (collection),
- operation of three transfer stations (redirection to landfill),
- operation of a municipal "energy from waste" incinerator (SWARU - solid waste reduction unit),
- operation of landfill sites (Glanbrook, Burlington, former Upper Ottawa Street), and
- operation of sewage treatment plants and adjacent incinerator (Woodward Avenue STP, Skyway STP).

Consideration was also given to members of the general public who may enter high exposure areas through such activities as beach recreation, or biking, motorcycling etc., in the landfill area.

7.2 Solid and Liquid Waste Handling

The occupational critical group individuals for municipal waste handling are listed in Table 7.1. Individuals working with solid waste are primarily involved in the collection of municipal waste and its delivery to the appropriate components of the waste management system. These include garbage-collectors, truck drivers, loaders, sorters, cleaners, operators, and engineers. In general, the majority of these workers handle

TABLE 7.1: INDIVIDUALS WORKING IN HAMILTON/BURLINGTON MUNICIPAL WASTE TREATMENT SYSTEMS EXPOSED TO RADIOISOTOPES

Waste System Component	Exposed Individual	Exposure Average Distance	Exposure Duration (hours/day)	Exposure Conditions - General	Comments
Bulk Handling	Garbage Collector	1 m	6	- outdoor work - may be shielding factor from truck's steel walls	- 2 hour travel time with empty truck
	Truck Driver	1 m	6	- truck approx. 6m x 2.5m x 2.5m	- rotates work with partner
Transfer Station	Loader	3 m	8	- waste in 2 piles, 10m high, 20m base, in open-faced concrete enclave - front-end loader used	
	Truck Driver	3 m	4	- truck 10m x 2.5m x 3m - may be shielding factor from truck	- 1/2 time with empty truck
Municipal Incinerator (SWARU)	Loader	3 m	6	- front-end loader - raw waste in piles 10m high x 20m base in concrete building pushed into open pit	
		3 m	2	- ash in piles 3m high x 10m base	- ash slurry spread over yard - ash desicating on loader (may be inhalation
	Sorter	1 m	8	- conveyor belt speed = 1 m/min - conveyor 10m wide, 30m length, 0.5 m deep @ 45° angle to sorter on bridge	- long rakes used to remove large objects
	Truck Driver		4	- truck 6m x 2.5m x 2.5m - may be shielding factor from truck walls	- 1/2 time with empty truck - ash desication in cab of truck - may be ash inhalation
Sanitary Landfill	Bulldozer Operator	1 m	8	- open pit - outdoors - may be shielding factor from dozer	- ash may desicate and result in inhalation
	Spreader	1 m	8	- open pit - outdoors - pulls scraper with bulldozer - may be shielding factor from bulldozer	- spreads 2.5 cm clay cover over waste - clay shielding factor
Sewage Treatment Plant	Operator	2 m	1	- primary clarifier - 77m x 112m x 3.5 m - aerators - 110m x 157m x 3m - secondary clarifier - 293m x 298m x 4m	- 0.2 m sludge on bottom - minimal aerosol - 0.2 m sludge on bottom - walkways 1.5m above water - exposure distance to mid-body point
	Operator	1 m	8	- vacuum filter dewatering room - open sludge filter feed tank - open conveyor belt to incinerator	- sludge on floor and walls - very warm / humid conditions
	Loader	3 m	2	- crane with "clam-shell" - ash in open concrete pit 10m x 10m x 5m	- ash dry, rust coloured - ash spread on ground above pit - inhalation of air-borne ash
	Truck Driver	1 m	2	- 6m x 2.5m x 2.5m open dump truck - may be shielding from truck	- inhalation of air-borne ash

municipal refuse by re-directing its flow through the various components of the waste system. As a result they tend to be in very close proximity to the raw waste and are exposed for a significant proportion of their daily 8-hour shift. Only the garbage collectors handle the waste manually, while other occupations employ indirect handling of the waste using front-end loaders or other equipment. Furthermore, all of the front-end loaders observed in field investigations, except one, had glass and metal cabs. This would tend to provide an element of shielding for the operator (Belanger, et al., 1979).

Some related occupations have not been included in the critical group. These include cleaners in the municipal incinerators who work in a variety of environments; some of which are cleaning up in areas where other critical group individuals have been considered. Since their exposure time is significantly less than that of the primary occupation, their dose is expected to be less than sorters and loaders. Control room operators, who work in a steel and glass control room near the boilers in the municipal incinerator, have not been included because of the shielding factor of the brick and steel boiler walls and the additional shielding of their control room walls.

Individuals working in the liquid waste system are primarily exposed to radioisotopes in the operation of two sewage treatment plants. These personnel are listed in Table 7.1. The Hamilton STP has an incinerator while the Skyway STP does not. Occupational critical group individuals associated with the handling of ash are discussed in Section 7.3.

Sanitary sewer maintenance personnel have not been included since most of their work is conducted above ground, where the fill and asphalt provide significant shielding from radiation. Television cameras are used to inspect sewer pipes to minimize the amount of time spent in man-holes and sewers. Because these personnel are only occasional exposure groups their exposure is significantly less than STP workers. Accordingly, they are not considered an occupational critical group in this report.

7.3 Incineration Ash Handling - SWARU and Woodward STP

Table 7.1 lists various personnel associated with incineration of waste. The occupational critical group is involved in the loading and unloading of ash from the STP and SWARU. Ash is not handled manually by any of the loaders or drivers. Front-end loaders or cranes are used where the operator is enclosed in a cab. Inhalation of airborne ash particles is, therefore, a possibility.

For the worker at SWARU the ash is wetted down before stockpiling in an open yard. It was observed during on-site investigations that this wetted ash was piled up in the yard by a front-end loader, and that the ash-sludge had flowed in streams, spreading out in a thin layer of wet ash over the yard. As a result, dessication of ash and airborne dust may be likely when climatic conditions are warm and dry. The same front-end loader that manipulated this ash is also used to pile raw garbage from incoming trucks, therefore, some ash may be spread in the pit area where sorters are working.

Ash is disposed by truck to the sanitary landfill, spread by a bulldozer operator, and covered with 2.5 cm of clay parent material by a "scraper". The bulldozer and "scraper" operators comprise the occupational critical group at the landfill. Municipal engineers who inspect the landfill and take weekly samples of run-off and leachate, as well as the several truck drivers who bring incinerator ash or garbage, have minimal exposure to incinerated waste and have been excluded from consideration in the occupational critical group due to this.

Ash at the sewage treatment plant is not wetted-down and is stored in open concrete pits. One day per week is spent loading ash onto trucks by a crane operator where it is delivered to a local contractor, mixed with granular material and used for roadbeds. On-site observations indicated that dry ash was spread over the ground above the pit and around the crane, giving strong indication of airborne dust and possible inhalation by critical individuals. The observed ash was rust coloured, indicative of oxidizing ferrous metals. Interviews with Municipal (Region of Hamilton-Wentworth) personnel revealed that the sanitary landfill is not willing to accept the ash due to the dusty conditions it creates in the landfill.

Although there is some exposure to the contractor's construction labourers to STP ash during roadbuilding, the ash constitutes 5% of the fill material. Therefore this exposure is significantly less than the group handling the ash at the STP (loader and truck driver). As a result, these construction workers are not listed in Table 7.1 as part of the occupational critical group.

7.4 Others

No industrial sources of radioactive waste entering the municipal waste management system could be identified in the region; therefore, no occupational critical group was

identified relevant to this sector. Furthermore, McMaster University has a research reactor, but radioactive waste is stored at Chalk River, according to AECB requirements. As a result, no occupational critical group individuals were identifiable relevant to wastes from the research reactor. Occupational exposure to radioisotopes through university and medical uses are not within the scope of this study. As a result, all occupational critical group workers identified are associated with occupational exposure in the various waste management systems of the Hamilton-Burlington region.

Incidental exposure to radioisotopes is possible through intrusion by the public into components of the waste system. At unguarded, closed landfills, such as Upper Ottawa Street, incidental incursions can occur from hikers, scavengers, and motocrossers. Such public enter the Burlington site as well. Since their exposure is minimal, in comparison with workers spending a 40-hour shift on the landfill every week, the dose to those incidental incursion groups were not considered. In the incinerator and sewage treatment components of the waste system, security is "tight" to preclude significant public incursion.

Other types of exposure may result from accidents. Trucks hauling waste may become involved in a collision and/or fire, exposing bypassers, firemen, police, and tow-truck operators. Spills in university or hospital laboratories may expose janitorial staff or bypassers to radioisotopes with very short half-lives and very low activity levels. Effluent from sewage treatment plants may wash-up on-shore, exposing people on the beach. As a result, there are many people in various situations that could be exposed to radioisotopes due to accidents and mishaps etc. Since their time of exposure is much lower than that for workers exposed to radioisotopes in the occupation settings given in Table 7.1, doses were not calculated for these groups.

SECTION 8

DOSE ESTIMATES FOR PERSONNEL INVOLVED IN WASTE HANDLING

8.0 DOSE ESTIMATES FOR PERSONNEL INVOLVED IN WASTE HANDLING

8.1 Introduction

Personnel involved in the handling of wastes at the waste incinerators, sewage treatment plants and landfill sites are not Atomic Radiation Workers. Radiation doses received by them as a result of exposure to low levels of radioactive materials in municipal wastes that they handle are not monitored. Because of their much closer proximity to the wastes compared to other members of the public, these individuals consititute the critical group with respect to external exposure and inhalation pathways.

In this section, radiation exposure pathways for municipal waste handlers are identified and dosimetric models for this occupational critical group are developed. Doses received by waste handlers are estimated.

Dosimetric models used tend to be somewhat conservative so that doses calculated may be regarded as upper limit estimates. Because of the low doses involved and difficulties in rigorously defining exposure geometries for external dose calculations, approximations rather than rigorous analytic solutions of external dosimetry models are generally used. These approximations are judged to be reasonable and will not result in underestimates of doses.

8.2 Exposure Pathways for Municipal Waste Handlers.

Exposure pathways are outlined in Table 7.1 (Section 7).

8.3 External Dosimetry Models for Municipal Waste Handlers

8.3.1 Relationship Between Effective Dose and Photon Flux Density

For exposure to a given radioisotope, the effective dose to the receptor is proportional to the photon flux density (in gamma photons per unit area per unit time) at the receptor location. The following relationship holds:

$$H = wD_a$$
$$= w\phi E\, u_a\, (1.6 \times 10^{-13})\, (10^3)\, (3.6 \times 10^3)$$
$$= 5.76 \times 10^{-7}\, w\phi E\, u_a \qquad (8.1)$$

where H = effective dose rate to receptor (Sv/h);
D_a = absorbed dose rate in air (Gy/h);
w = conversion factor from absorbed dose in air to effective dose (Sv/Gy);
ϕ = gamma photon flux density (photons·cm^{-2}·s^{-1});
E = total emitted gamma energy per disintegration (MeV);
u_a = mass absorption coefficient of gamma photons in air (cm^2/g);
1.6×10^{-13} = energy conversion factor (J/MeV);
10^3 = number of gm per kg; and
3.6×10^3 = number of seconds per hour.

A mean value of w over the energy range of 0.05 MeV to 2 MeV may be conservatively taken to be 0.8 (CEC, 1979, p. 72). The value of u_a is also a slow varying function of gamma energy at energies above 0.05 MeV. For example, at 0.06 MeV, its value is 0.0292 cm^2/g whereas at 2 MeV, its value is 0.0234 cm^2/g (Radiological Health Handbook, 1970). A mean value of 0.03 cm^2/g may be conservatively used as an average for all photon energies of interest. Putting these values of w and u_a into Equation 8.1, one obtains:

$$H = 1.38 \times 10^{-8} \phi E \ \text{Sv/h} \qquad (8.2)$$

The value of E for a given radioisotope is:

$$E = \sum_i f_i E_i \qquad (8.3)$$

where, E_i = gamma energy of transition i (MeV);
f_i = fractional abundance of transition i.

Values of E_i, f_i and E for the gamma-emitting radioisotopes of interest are given in Table 8.1. The relationships between the photon flux density ϕ and various source-receptor exposure geometries of interest are developed in the following sections. Annual

TABLE 8.1: GAMMA-EMITTING RADIOISOTOPES

Radionuclide (Half-life)	Gamma Energy E_i (MeV)	Fractional Abundance f_i	Mass Attenuation Coefficient μ_{mi} (cm^2/g)	Total Energy $E = \sum_i f_i E_i$ (MEV)	$\sum_i f_i/\mu_{mi}$ (g/cm^2)
Cr-51 (27.7 d)	0.32	0.10	0.113	0.032	0.88
Co-57 (272 d)	0.122	0.856	0.16		
	0.136	0.11	0.153	0.119	6.07
Zn-65 (245 d)	0.511	0.034	0.096		
	1.115	0.51	0.067	0.586	7.97
Ga-67 (78 h)	0.093	0.38	0.174		
	0.184	0.24	0.139		
	0.30	0.19	0.117		
	0.394	0.054	0.105	0.158	6.05
Se-75 (118 d)	0.066	0.011	0.198		
	0.097	0.031	0.171		
	0.121	0.16	0.16		
	0.136	0.54	0.153		
	0.265	0.58	0.122		
	0.28	0.25	0.12		
	0.401	0.12	0.105	0.368	12.7
Tc-99m (6 h)	0.14	0.89	0.151	0.125	5.89
I-125 (60.3 d)	0.035	0.067	0.30	0.00235	0.223
I-131 (8.04 d)	0.08	0.026	0.185		
	0.284	0.06	0.119		
	0.364	0.81	0.108		
	0.637	0.072	0.088		
	0.723	0.018	0.083	0.373	9.18
Tl-201 (74 h)	0.135	0.0160.155			
	0.167	0.09	0.144	0.0172	0.728
Am-241 (432 y)	0.06	0.36	0.207	0.0216	1.74

Note: Only gamma photons greater than 1% abundance are given.
Source: Lederer, et al., 1978; Radiological Health Handbook, 1970.

occupational dose is given by the product of the effective dose rate H (Sv/h) and the total occupational exposure time per year in hours.

8.3.2 Source-Receptor Geometrics

With reference to the various source-receptor exposure situations at waste handling facilities and landfill sites discussed in Section 8.2, appropriate source geometries have been selected to model the exposure situations. These are given below:

	Source Geometry	Exposure Situation Modelled
(a)	Semi-infinite thick slab	- Exposure of transfer station and SWARU loaders to garbage and ash piles outdoors
		- Exposure of Sewage Treatment Plant operators to dissolved and suspended radioactivity in clarifier and aerator tanks.
(b)	Solid cylinder	- Exposure of truck drivers and garbage handlers to garbage and ash contained in garbage trucks.
		- Exposure of Sewage Treatment Plant operators to sewage sludge slurry tank during dewatering operations.
(c)	Hollow cylinder	- Exposure of Sewage Treatment Plant operators to sewage sludge on dewatering drum.
(d)	Infinite plane	- Exposure of workers to ground deposits at waste handling facilities.
		- Exposure of sorters to refuse on conveyor belt at the SWARU.

(e) Soil uniformly contaminated to infinite depth -Exposure of workers at landfill site.

In addition, workers are exposed to gamma radiation from airborne radioisotopes in the working environment.

Methodologies and parameter values are given in the following sub-sections for calculating the photon flux densities ϕ for various geometries. The value of ϕ is then inserted in Equation 8.2 to calculate the effective dose rate. In the case of the infinite plane source and uniformly contaminated soil, the effective dose rate is calculated directly. Common symbols used in the equations are defined below:

ϕ = photon flux density (photons·cm^{-2}·s^{-1});

C_v = source concentration (Bq/cm^3);

f_i = fractional abundance of gamma photon of energy E_i MeV (see Table 8.1);

ρ = density of source material (g/cm^3);

u_{mi} = mass attenuation coefficient for gamma photon of energy E_i (cm^2/g);

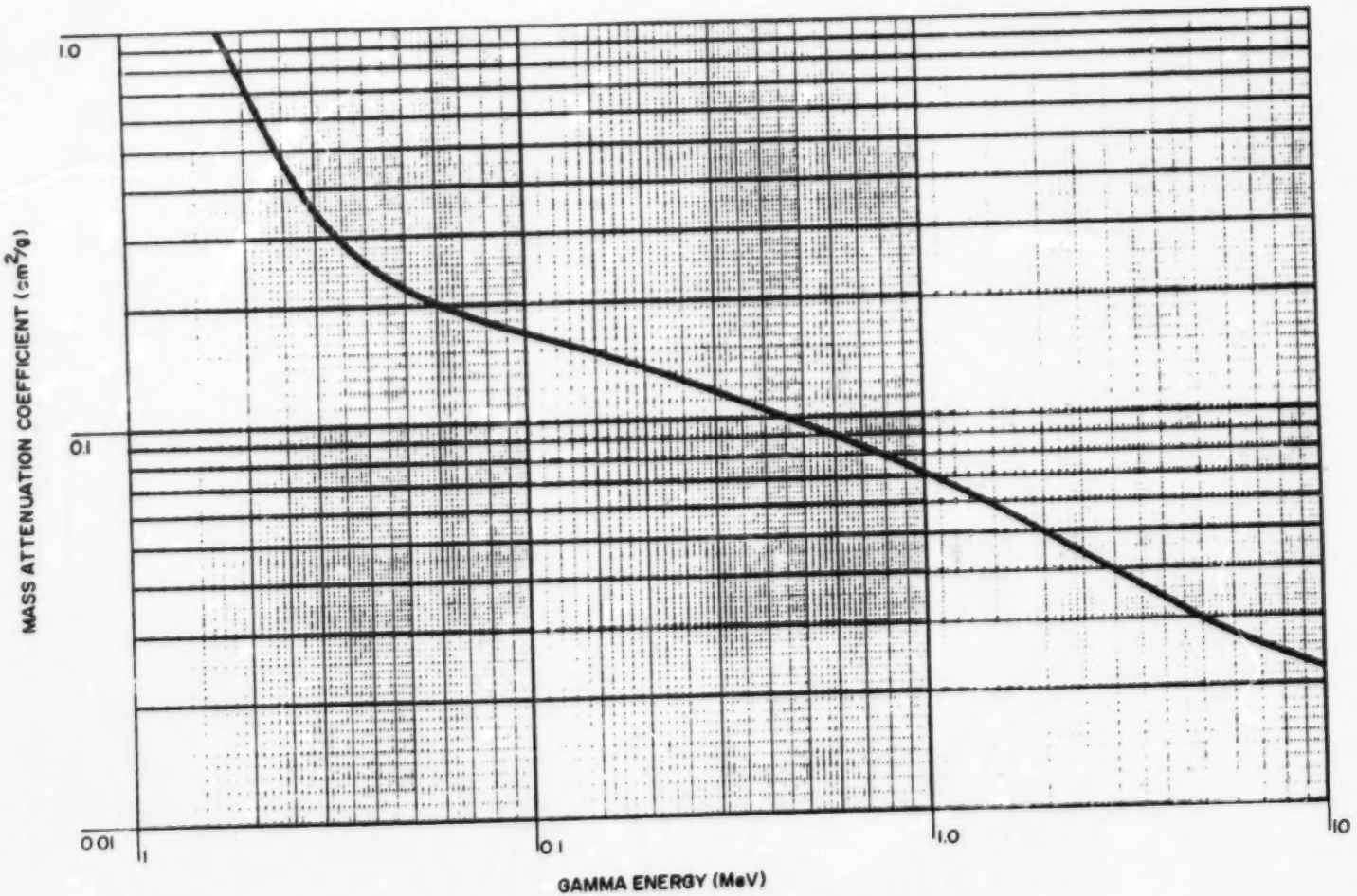
u_i = $u_{mi}\rho$ = linear attenuation coefficient for gamma photon of energy E_i (cm^{-1});

B = build-up factor : 3.

The mass attenuation coefficients for a wide range of materials (water, air, soft tissue, polyethylene, glass, soil, aluminum) are substantially similar, particularly at energies above 0.1 MeV. In this study, values for water will be used for all forms of mixed garbage and ash. These values are plotted in Figure 8.1 as a function of gamma photon energies (Radiological Health Handbook, 1970).

The build-up factor B allows for multiple scattering of gamma rays occurring within the source material itself, which in effect increases the photon flux density over that calculated from the simple exponential attenuation law. The value of B is a complex function of the source geometry and photon energy. For the infinitely extended source, B may be shown to lie in the range of 2 to 4, for unit density material and photon energies in the range of 0.05 to 2 MeV (Jaeger et al., 1968, p. 392). An average B value of 3 is judged to be sufficiently conservative for all photon energies in this study.

FIGURE 8.1 Mass Attenuation Coefficient as a Function of Gamma Energy



(a) **Semi Infinite Thick Slab Source**

From Jaeger et al. (1968, p. 374).

$$\phi = \frac{BC_v}{2\rho}\sum_i f_i/u_{mi} \tag{8.4}$$

where the summation extends over all gamma transitions of a given radioisotope. Values of the summation for all gamma-emitting radioisotopes of interest to this study are given in Table 8.1.

(b) **Cylindrical Volume Source**

The cylindrical source geometry and dimension labelling are shown in Figure 8.2.

At P_1 (derived from Jaeger, et al., 1968, p. 384-385)

$$\phi = \left[\frac{BC_v \quad (1-\cos\theta_1) + (1-\cos\theta_2)}{4\rho}\right]\sum f_i/u_{mi} \tag{8.5}$$

Note that in Figure 8.2, the angle θ_2 is defined by an effective cylinder height $h' = 3/u_i$ where u_i is the linear attenuation coefficient for photon with energy E_i.

This position corresponds to that of a truck driver with the truck contents approximated by the cylindrical volume source.

At P_3 (Jaeger, et al., 1968, p. 382)

$$\phi = \frac{BC_v R}{2\pi}\sum_i f_i \cdot G(k,\beta,u_i R) \tag{8.6}$$

where $k = h/R$, $\beta = b/R$ and the summation extends over all gamma transitions of a given radioisotope. The function G for various k, β and $u_i R$ values are plotted in Figure 8.3. The dimensional variables R, h and b are defined in Figure 8.2.

FIGURE 8.2

Geometry for Cylindrical Source

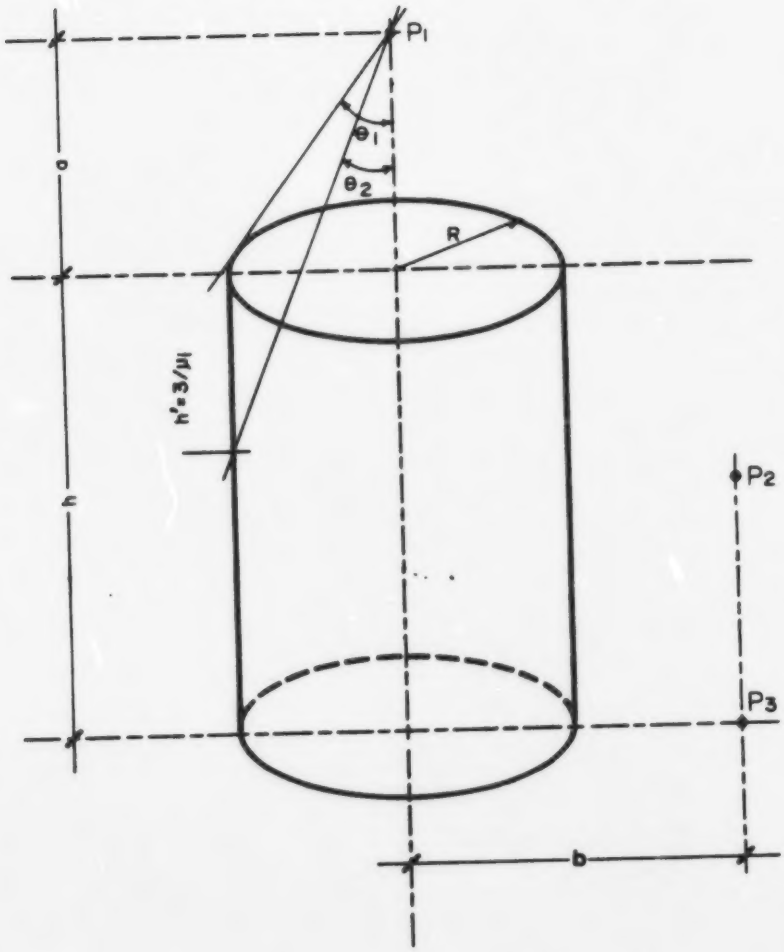
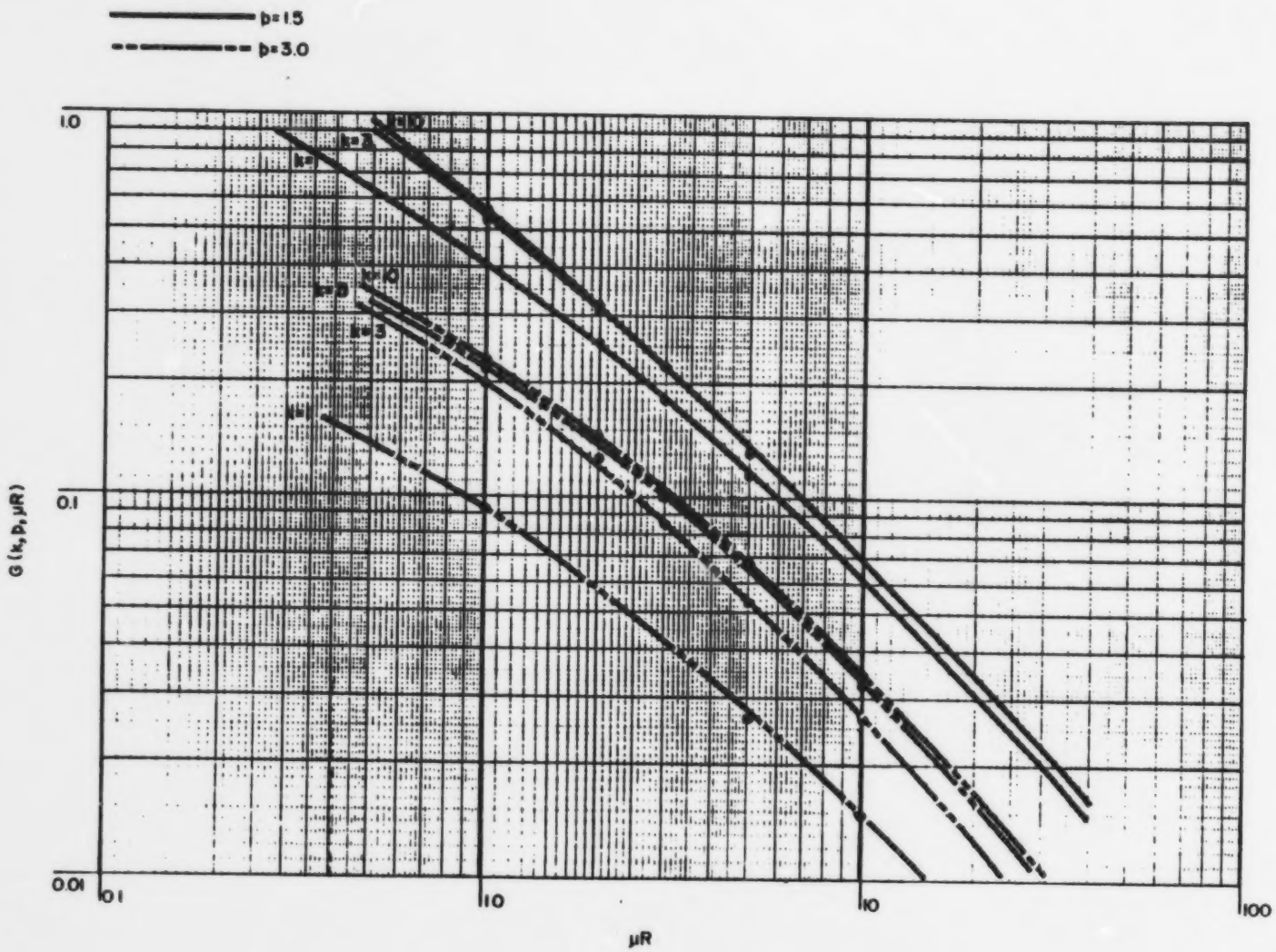


FIGURE 8.3 The G Function for Cylindrical Volume Source Calculations



This position corresponds to that of the garbage handler working at the loading end of the garbage truck.

At P_2 (Jaeger et al., 1968, p. 382)

$$\phi = \frac{BD_v R \sum_i f_i \cdot H(k', \beta, u_i R)}{2\pi} \qquad (8.7)$$

This equation is similar to that for P_3 above except that in the function G, $k'=h/2R$. This position corresponds to that of the operator in the Sewage Treatment Plant working in the vicinity of cylindrical volume sources.

(c) Hollow Cylinder (Cylindrical Surface Source)

In this geometry, radioactive material is deposited as a thin layer on the surface of a hollow cylindrical drum. It describes the sludge dewatering drum at the Sewage Treatment Plant. From Jaeger, et al. (1968), p. 371, it may be deduced that:

$$\phi = \frac{C_v d \sum_i f_i}{2} W(k, \beta) \qquad (8.8)$$

where d is the thickness of the sludge deposit (cm), $k=h/R$, and $\beta=b/R$. The function W for various k and β values are plotted in Figure 8.4. The dimensional variables R, h and b are defined in Figure 8.2.

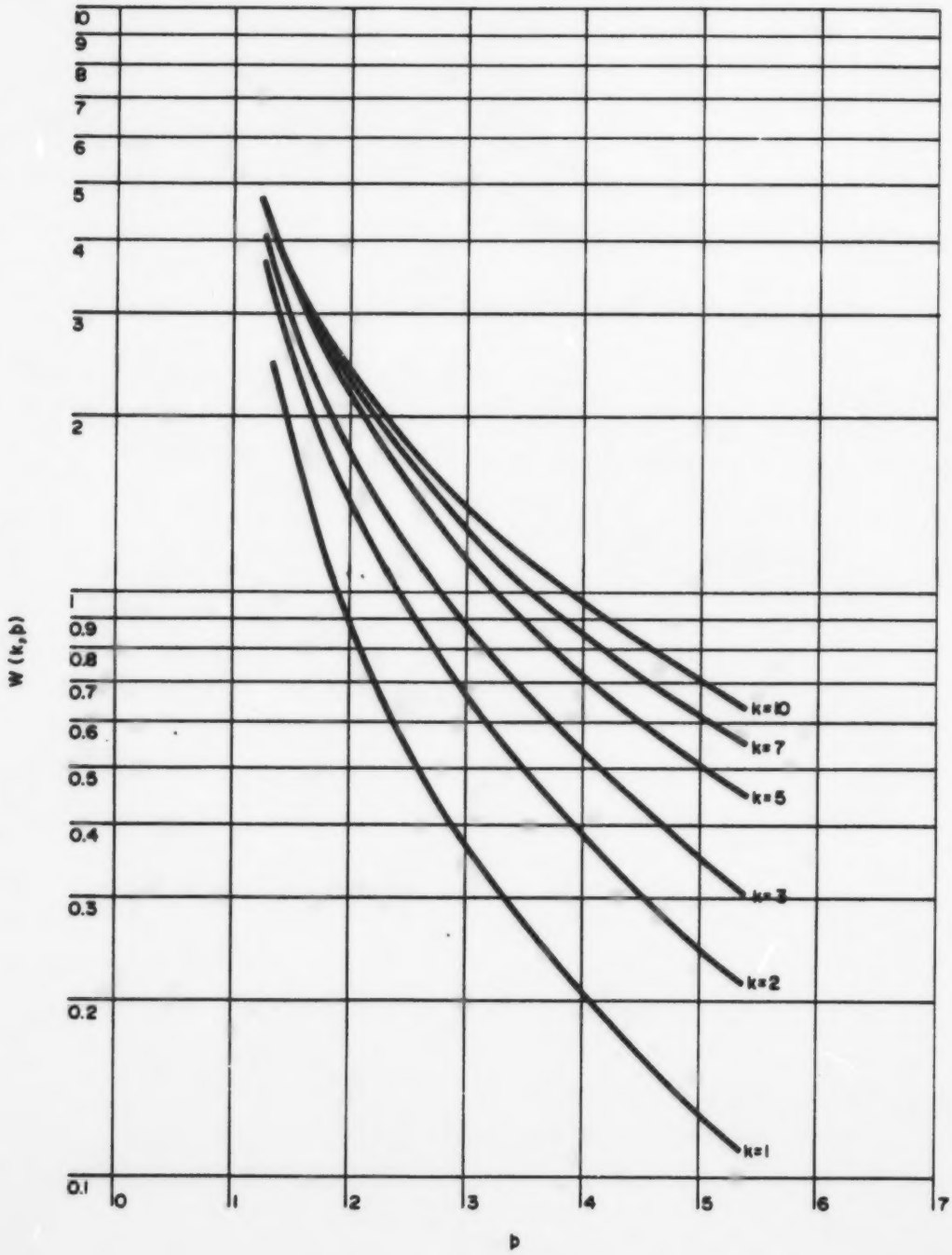
(d) Infinite Plane Source

For this geometry, the effective dose rate H is calculated directly, as follows:

$$\begin{aligned} H &= 10^4\, C_v d \cdot (DCF)_g / 8760 \\ &= 1.14\, C_v d \cdot (DCF)_g \qquad (8.9) \end{aligned}$$

where H = effective dose rate (Sv/h);
d = thickness of surface deposit (cm);

FIGURE 8.4 The W Function for Hollow Cylindrical Source Calculations



$(DCF)_g$ = Dose Conversion Factor for exposure 1 m above uniformly contaminated plane surface ($Sv \cdot a^{-1} \cdot Bq^{-1} \cdot m^2$);

10^4 = conversion from cm^2 to m^2;

8760 = number of hours per year

Values of $(DCF)_g$ for the radioisotopes of interest are given in Appendix C, Table C4.

(e) Uniformly Contaminated Soil

Beck and de Planque (1968) calculated the radiation field in air above soil uniformly contaminated with radioactive materials to infinite depth, using transport methods. Their results were given in exposure units of MeV/g-sec, for a uniform source strength of 1 gamma photon per cm^3 per sec. This was converted to more convenient exposure units in Sv/h and plotted in Figure 8.5, for exposure at 1 metre above ground. The effective dose rate for a given radioisotope H, in Sv/h, is:

$$H = C_v \sum_i f_i H_i \quad \text{Sv/h} \qquad (8.10)$$

where H_i = effective dose rate for gamma energy E_i obtained from Figure 8.5 (Sv/h);

f_i = fractional abundance of E_i;

C_v = radioisotope concentration in soil (Bq/cm^3).

The summation extends over all gamma transitions of the radioisotopes.

8.3.3 Dose Conversion Factors for Various Source-Receptor Geometries

The effective dose rates in Sv/h, normalized to unit source concentration of 1 Bq/cm^3, for various source-receptor exposure geometries have been calculated and are summarized in Table 8.2 for the gamma-emitting radioisotopes of interest to this study. Calculations are based on exposure geometries given in Section 8.2.

8.3.4 External Dose to Workers from Contaminated Air

The transfer parameter $P(e)_{19}$ relating the annual dose ($Sv \cdot a^{-1}$) to the annual average concentration of the radioisotope in air ($Bq \cdot m^{-3}$) is:

FIGURE 8.5 Effective Dose Rate from Soil Uniformly Contaminated to Infinite Depth to a Source Strength of 1 Gamma Photon per cm^3 per second

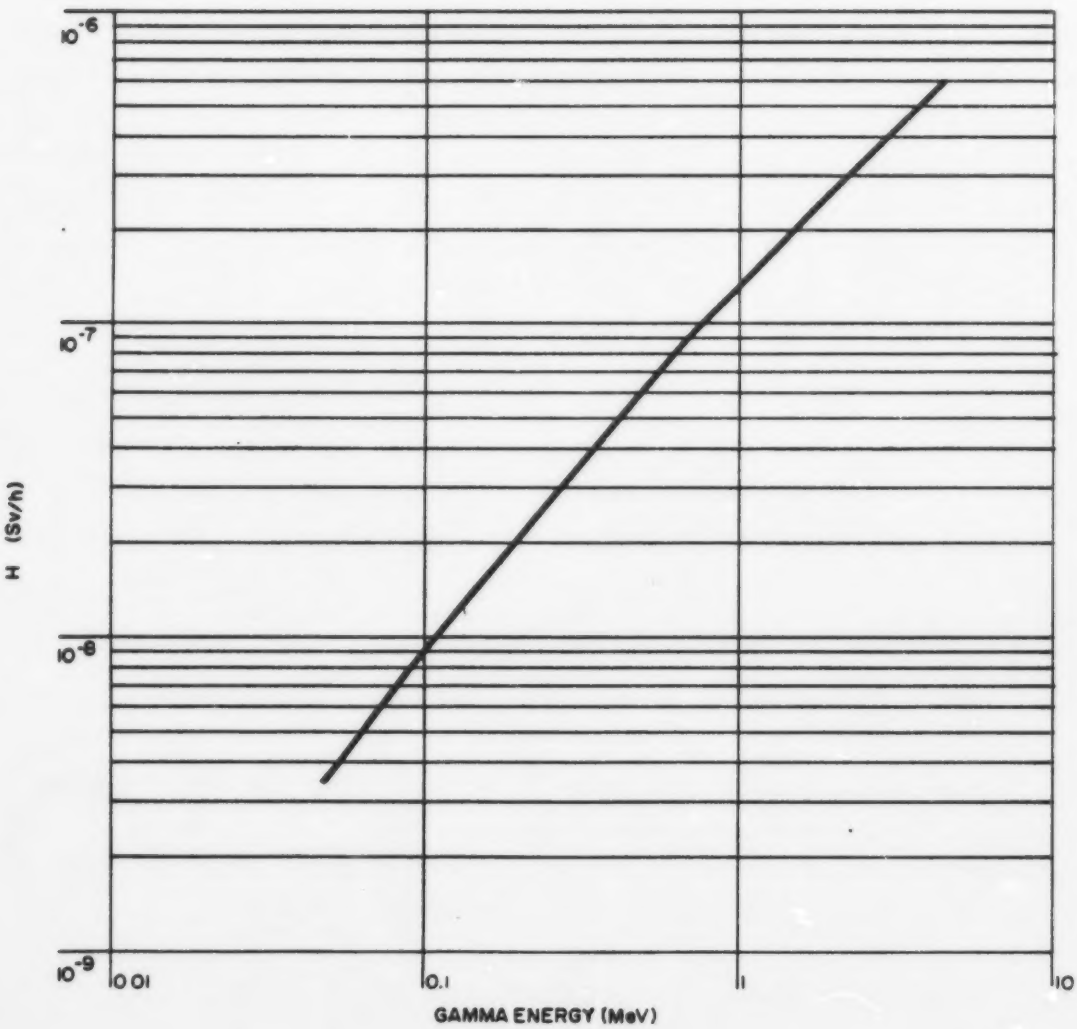


TABLE 8.2: EFFECTIVE EXTERNAL DOSE RATE (Sv/h) FOR UNIT CONCENTRATION (1 Bq/cm^3) OF RADIOISOTOPE IN MUNICIPAL WASTE; VARIOUS SOURCE-RECEPTOR GEOMETRIES

Source-Receptor Geometries	Effective Dose Rate (Sv/h)									
	Cr-51	Co-57	Zn-65	Ga-67	Se-75	Tc-99m	I-125	I-131	Tl-201	Am-241
1. Truck Drivers										
Truck Size 6m x 2.4m x 2.4m										
- waste density = 0.1 g/cm^3	1.2E-9	3.2E-8	1.9E-7	4.3E-8	2.0E-7	3.3E-8	2.7E-11	1.4E-7	5.6E-10	1.8E-9
- waste density = 1 g/cm^3	1.8E-10	4.9E-9	2.9E-8	6.5E-9	3.1E-8	5.0E-9	3.7E-12	2.2E-8	8.4E-11	2.6E-10
2. Garbage Collectors										
Truck size 6m x 2.4m x 2.4m										
- Waste density = 0.1 g/cm^3	1.1E-9	3.0E-8	1.6E-7	3.8E-8	1.8E-7	3.0E-8	2.3E-11	1.3E-7	5.0E-10	1.6E-9
3. Loaders at Transfer Station and SWARU										
- Waste density = 0.1 g/cm^3	5.8E-9	1.5E-7	9.7E-7	2.0E-7	9.7E-7	1.5E-7	1.1E-10	7.1E-7	2.6E-9	7.8E-9
- Waste density = 1 g/cm^3	5.8E-10	1.5E-8	9.7E-8	2.0E-8	9.7E-8	1.5E-8	1.1E-11	7.1E-8	2.6E-10	7.8E-10
4. Sorters at SWARU										
- Waste density = 0.1 g/m^3	5.2E-8	2.2E-7	8.4E-7	2.5E-7	6.6E-7	2.3E-7	3.8E-8	6.2E-7	3.1E-8	4.6E-8
- Waste thickness = 50 cm										
5. Sewage Plant Operators										
(a) Above clarifier or aerator tanks*	5.8E-10	1.5E-8	9.7E-8	2.0E-8	9.7E-8	1.5E-8	1.1E-11	7.1E-8	2.6E-10	7.8E-10
(b) Beside dewatering drum	2.3E-11	8.9E-10	2.5E-9	1.1E-9	4.8E-9	8.6E-10	1.2E-12	2.9E-9	1.4E-11	6.0E-11
(c) Beside sludge slurry tank (density - 1 g/cm^3)	2.8E-11	7.3E-10	4.6E-9	9.0E-10	4.5E-9	7.3E-10	5.2E-10	3.4E-9	1.3E-11	3.9E-11
6. Workers Exposed Over Contaminated Ground										
(a) Sludge Workers - Surface deposit thickness = 0.5 cm	5.3E-10	2.2E-9	8.5E-9	2.5E-9	6.5E-9	2.3E-9	3.8E-10	6.3E-9	3.0E-10	4.5E-10
(b) Other Workers - Surface deposit thickness = 2 cm	2.1E-9	8.8E-9	3.4E-8	1.0E-8	2.6E-8	9.1E-9	1.5E-9	2.5E-8	1.2E-9	1.8E-9
7. Landfill Site Workers	3.7E-9	1.1E-8	7.9E-8	1.7E-8	4.0E-8	1.2E-8	1.5E-10	5.3E-8	1.7E-9	1.7E-9

* For this source-receptor geometry, unit concentration refers to 1 Bq/cm^3 in the clarifier and aerator water.

$$P(e)_{19} = fu\,(DCF)a\ Sv \cdot a^{-1} \cdot Bq^{-1} \cdot m^3$$

in which:

fu = occupancy factor, or fraction of the time the worker is exposed to the contaminated air. These are given in Table 8.4; and

$(DCF)_a$ = dose conversion factor for a semi-infinite cloud ($Sv \cdot a^{-1} \cdot Bq^{-1} \cdot m^3$). These dose conversion factors are given in Table B3 (Appendix B).

8.4 Internal Dosimetry Model for Municipal Waste Handlers

The major internal exposure pathway for municipal waste handlers is inhalation. The annual committed dose from inhalation of a given radioisotope is given by:

$$H(Inh) = C_a I_a T_a (DCF)_i \qquad (8.11)$$

where C_a = radioisotope concentration in air (Bq/m^3);
I_a = air intake rate (m^3/h);
T_a = exposure time per year (h/a);
$(DCF)_i$ = Dose Conversion Factor for inhalation intake (Sv/Bq);
H(Inh) = effective inhalation committed dose (Sv/a).

The air intake rate I_a is 1.2 m^3/h (ICRP, 1975). Values of $(DCF)_i$ for the adult are given in Appendix B, Table B1. The exposure times T_a for various occupational groups are discussed in Section 8.2.

Airborne concentrations of suspended particulates may be conservatively calculated by assuming that the dust loading in the workplace is derived entirely from resuspended municipal waste, such as ash. With this assumption,

$$C_a = MC_v / \rho \qquad (8.12)$$

where M = dust loading in air (g/m^3);

C_v = radioisotope concentration in municipal waste (Bq/cm^3);

ρ = density of municipal waste (g/cm^3).

The density of ash is taken to be 1 g/cm^3. The dust loading in surface air in populated areas is about 10^{-4} g/m^3 (UNSCEAR, 1977, p. 58). It is assumed in the work place that the value of M is 2×10^{-4} g/m^3. The Region's monitoring of dust levels at the Burlington landfill site (used in predictions of impacts for a proposed new site adjacent to this) indicate maximum levels of 2×10^{-4} g/m^3, corresponding to our estimate (Senes, 1985). In the Senes estimates, dust levels fall to below the 1×10^{-4} g/m^3 Ontario standard within 300 m of the site boundary and 0.5×10^{-4} g/m^3 within 1 km. Since the site is isolated from residential areas, general population dust loading would be well below this level and insignificant from a radioisotope dosimetry perspective.

For the potentially volatile radioisotopes H-3 (H_2O), C-14 (CO_2), I-125 and I-131 (I_2), it is assumed that about 1% of the radioactivity in waste is vapourized in airborne form per day.

$$\text{Release rate} = 0.01\, C_v M_w \quad \text{Bq/day} \tag{8.13}$$

where C_v = radioisotope concentration in waste (Bq/cm^3);

M_w = waste throughput rate for the waste handling facility (cm^3/day).

The highest exposure will generally occur indoors, due to confinement of released radioactivity in buildings. The steady state concentration of volatilized radioisotope indoors is:

$$C_a = \frac{0.01\, C_v M_w}{24\, nV} = 4.2 \times 10^{-4}\, \frac{C_v M_w}{nV} \tag{8.14}$$

where Ca = airborne concentration (Bq/m^3);

V = volume of building (m^3)

n = number of air changes per hour.

The committed dose H (Sv/a) is calculated according to Equation 8.11.

For workers working above the aeration tanks, a potential exposure hazard is inhalation of aerosols produced from the tank. The aerosol concentration above the tank is assumed to be 10 g of tank water per m^3. Hence, the airborne radioactivity concentration is :

$$C_a = 10\ C_w \quad Bq/m^3 \tag{8.15}$$

where C_w is the radioactivity concentration in the aeration tank water (Bq/g). The committed dose is calculated from Equation 8.11.

8.5 Dose Calculations

8.5.1 External Dosimetry

8.5.1.1 External Dosimetry from Contaminated Materials

The external dosimetry is calculated utilizing formula 8.2:

$$H = 1.38 \times 10^{-8}\ \phi E \quad Sv/h$$

Once the effective dose rate to receptor (H) is determined in Sv/h, the annual dose rate is calculated by multiplying by the number of hours per year exposed from Table 8.4.

The total emitted gamma energy per disintegration (E) for each radioisotope is presented in Table 8.1. The gamma photon flux density (ϕ) is the remaining factor which must be calculated separately for each source with formulae varying with the geometry of the sources. These are discussed in the following.

<u>Exposure of Transfer Station and Incinerator Loaders</u>

Workers at the transfer station and incinerator will be exposed to solid wastes piled awaiting handling or processing and to the ash from the incinerator. These waste materials are modelled as a semi-infinite thick slab source where the photon flux density (ϕ) is calculated using the equation 8.4:

$$\phi = \frac{B\, C_v \sum_i f_i / u_{mi}}{2\rho}$$

where the buildup factor (B) is assumed to be 3, the density of source material (ρ) between 0.1 and 1.0 g/m^3 (Table 8.2), the source concentration (C_v) is taken from Appendix D, and the fractional abundance (f_i) and mass attenuation co-efficient (u_{mi}) are taken from Table 8.1.

Exposure of Sewage Treatment Plant Operators from Liquids in Clarifier and Aerator Tanks

This dosimetry is calculated using a semi-infinite thick slab model as discussed above.

Exposure of Truck Drivers and Garbage Handlers

The exposure of garbage or ash truck drivers and exposure of handlers/sorters were calculated using a Solid Cylindrical Volume Source model. As illustrated in Figure 8.2 there are three exposure locations (P_1, P_2, P_3) for which different model formulae are utilized. These relate to positions in which workers would normally be found relative to the source. P_1 represents the garbage truck driver while P_3 represents the garbage handler/loader. At P_1 the photon flux density (ϕ) is calculated using formula 8.5:

$$\phi = \frac{BC_v \left[(1-\cos\theta_1) + (1-\cos\theta_2)\right] \sum f_i / u_{mi}}{4\rho}$$

The factors B, C_v, ρ, f_i and u_{mi} are as defined for the semi-infinite thick slab model above. The geometry for determining the exposure angles (θ_1 and θ_2) is illustrated in Figure 8.2.

The P_3 garbage handler/loader exposure is determined using formula 8.6:

$$\phi = \frac{B\, C_v\, R \sum_i f_i\; G(k,\phi,u_i,R)}{2\pi}$$

The parameters B, C_v, and f_i are as defined above. R is the cylinder radius and the linear attenuation coefficient (u_i) = the mass attenuation coefficient (u_{mi}) times the density of source material (ρ). The k, and p values are defined by k=h/R and p=b/R with h, R and b dimensious fo the cylinder as depicted in Figure 8.2 The function G for various k,p and $u_i R$ is depicted in Figure 8.3.

Exposure of Sewage Treatment Plant Operators from Sludge Slurry

This exposure is calculated using the P_2 position from Figure 8.2. The equation 8.7 is similar to 8.6 above with the only difference being that $k' = h/zR$.

$$D = \frac{B\, C_v\, R \sum_i f_i\; G\,(k', p, u_i\; R)}{2\pi}$$

Exposure of Sewage Treatment Plant Operators at Sludge Dewatering Drum

This exposure calculation uses the hollow cylinder model defined by the Equation 8.8.

$$D = \frac{Cvd\;{}_i f_i\;\; W(k,p)}{2}$$

In this equation C_v, f_i, k and p are as previously defined. The d is the thickness of the sludge deposit in cm. The function W is plotted in Figure 8.4.

Exposure of Workers to Deposits on the Ground or Incinerator Conveyer

Workers at the landfill site, in the vicinity of any ground deposits at waste handling facilities and sorters at the incinerator conveyer belt are exposed to ash in a manner calculated using an infinite plane source model, Equation 8.9;

$$H = 1.14\, C_v\, d\, (DCF)g$$

Where H, C_v and d are previously defined. The dose conversion factor for exposure one metre above the surfact (DCF)g is taken from Appendix B, Table B3.

8.5.1.2 External Dosimetry from Immersion in Contaminated Air

The annual dose ($Sv \cdot a^{-1}$) may be related to the average radioisotope concentration in air ($Bq \cdot m^{-3}$) at the workplace by the transfer parameter $P(e)_{19}$:

$$P(e)_{19} = (f_u)\,(DCF)_a \; Sv \cdot a^{-1} \cdot Bq \cdot m^3$$

where: f_u = occupancy factor, or fraction of time a worker spends in the workplace exposed to the unshielded radioisotope cloud;

$(DCF)_a$ = dose conversion factor for a semi-infinite cloud ($Sv \cdot a^{-1} \cdot Bq^{-1} \cdot m^3$), as given in Table B3 (Appendix B).

8.5.2 Internal Dosimetry

Several waste disposal workers may be exposed to airborne radioisotopes resulting in a dose through inhalation. At the sewage treatment plant, the sludge worker is exposed to volatile radioiodine, C-14 and H-3 from sludge in the dewatering room; the aeration tank operator is exposed to airborne radioactivity in aerosol; and the ash loader and ash truck driver may be exposed to airborne incinerator ash during the loading operation.

For the sludge worker, the concentration of volatile radioisotopes is calculated from Equation 8.14:

$$Ca = 4.2 \times 10^{-4}\, C_v\, M_w / nV$$

where: $C_v\, M_w$ is equal to the annual throughput of radioactivity in sludge, given in Table 4.2, divided by 8760, the number of hours in a year:

n is assumed to be three exchanges per hour; and
V is estimated to be 850 m^3 for the sludge dewatering room.

Based on these assumptions, concentrations of I-125, I-131, C-14 and H-3 in the sludge dewatering room may be calculated as shown in Table 8.3.

TABLE 8.3: ATMOSPHERIC CONCENTRATIONS OF RADIOISOTOPES IN WORKPLACES ($Bq \cdot m^{-3}$)

	Sewage Treatment			SWARU		Landfill	
Radio-isotope	Sludge Room	Aeration Tanks	Ash Loading Area	Yard	Main Building	Hamilton	Burlington
H-3	1.92E-2	1.00E-4	-	-	-	-	-
C-14	1.50E-2	4.46E-4	-	-	-	-	-
P-32	-	2.68E-4	3.22E-5	-	-	-	-
P-33	-	-	-	-	-	-	-
S-35	-	1.34E-4	2.97E-6	-	-	-	-
Cr-51	-	2.68E-4	9.22E-6	-	-	-	-
Co-57	-	1.79E-10	3.30E-12	-	-	-	3.87E-8
Ni-63	-	-	-	7.33E-7	3.67E-7	3.30E-7	7.78E-8
Zn-65	-	-	-	-	-	-	2.18E-8
Ga-67	-	5.83E-3	6.16E-5	-	-	-	-
Se-75	-	-	-	-	-	-	-
Tc-99m	-	9.51E-2	1.70E-29	-	-	-	-
I-125	1.31E-4	2.50E-3	1.16E-7	-	-	-	-
I-131	3.76E-4	7.14E-3	1.91E-7	-	-	-	-
Tl-201	-	5.18E-3	2.36E-9	-	-	-	-
Po-210	-	-	-	4.40E-7	2.20E-7	1.46E-7	1.22E-7
Am-241	-	-	-	2.63E-7	1.31E-7	1.67E-7	1.49E-7

For the aeration worker, concentrations of radioisotopes in the atmosphere above the aeration tanks are given by Equation 8.15:

$$C_a = 10\ C_w\ Bq \cdot m^{-3}$$

where: C_w is activity of radioisotope in the aeration tank liquor, calculated from values listed in Table 5.1 assuming a density of 1 $g \cdot cm^{-3}$ in sewage. The liquor, composed of wastewater and activated sludge, is assumed to form a hydrated aerosol composed of the wastewater and biological solids from the spray emanating from the tank.

Radioisotope concentration in the atmosphere above the aeration tanks are provided in Table 8.3.

For the truck driver and loader working with the incinerated sludge ash, atmospheric concentrations of radioisotopes may be calculated from Equation 8.12:

$$C_a = M\ C_v / \rho$$

where: M = $2 \times 10^{-4}\ g \cdot m^{-3}$ of ash,
ρ = density of ash, 1 $g \cdot cm^3$, and
C_v = radioisotope concentration in incinerator ash ($Bq \cdot cm^{-3}$) calculated from data in Table 5.1.

Radioisotope concentrations in the atmosphere at the ash loading area are listed in Table 8.3.

At the SWARU municipal incinerator, workers may be exposed to airborne radioisotopes in the main building (sorters, loaders) and in the yard where ash is stockpiled. Normally, there are no volatile radioisotopes (H-3, C-14, I-125, I-131) in municipal garbage, thus, only radioisotopes found in the ash require consideration here.

Atmospheric concentrations of radioisotopes may be calculated from Equation 8.12 for SWARU and landfill workers:

$$C_a = M C_v / \rho$$

where: M = dust loading in air, assumed to be 2×10^{-4} g·m^{-3} in the SWARU yard and at the landfill sites and half this value or 1×10^{-4} g·m^{-3} in the main SWARU building,

C_v is the radioisotope concentration in waste derived from Table 5.1 (Bq·cm^{-3}) and, and

ρ is the density of ash or landfill material, 1 g·cm^3.

Airborne radioisotope levels in the SWARU yard at the landfills, and in the main SWARU building, calculated according to these assumptions, are provided in Table 8.3.

There are no significant sources of volatile radioisotopes or airborne particulate radioisotope in raw municipal refuse; therefore, bulk handlers and transfer station workers receive no dose from inhalation.

Doses from inhalation of airborne radioisotopes at the workplace may now be estimated according to Equation 8.11:

$$H(inh) = C_a I_a T_a (DCF)_i$$

where: C_a are radioisotope concentrations given in Table 5.3,

I_a is 1.2 m^3· h^{-1},

T_a for the occupational groups, calculated from data presented in Table 7.1, are as provided in Table 8.4, and

$(DCF)_i$ are as provided in Table B1 (Appendix B).

The annual committed dose from inhalation of various radioisotopes by the various occupational groups are derived in the spreadsheets (Appendix H), columns X_{9i}.

TABLE 8.4: EXPOSURE TIMES ($h \cdot a^{-1}$) OF VARIOUS WORKERS

Worker		Exposure Period
Sewage Treatment:	Sludge Worker	2,000
	Aeration Tank Operator	750
	Ash Loader	250
	Truck Driver	500
SWARU Incinerator:	Sorter	2,000
	Loader: - indoors	1,500
	- outdoors	500
	Truck Driver	1,000
Waste Handlers	Garbage Collector	1,500
	Truck Driver	1,500
Sanitary Landfill Sites:	Bulldozer Operator	2,000
	Spreader	2,000

SECTION 9

TRANSFER PARAMETERS FOR AIRBORNE RELEASES

9.0 TRANSFER PARAMETERS FOR AIRBORNE RELEASES

9.1 Atmospheric Dispersion (P_{I1}, P_{L1}, P_{S1})

9.1.1 Average Atmospheric Concentrations in Hamilton-Burlington

A generic dispersion model was defined for determining ground level concentrations of radioisotopes resulting from the various atmospheric emissions. The major atmospheric source terms resulting in population dose are:

- the stack releases of Am-241 from the SWARU incinerator,
- stack releases of radioisotopes in the combustion of Hamilton sewage treatment plant sludge, and
- releases of H-3 as HTO and C-14 as $C\text{-}14O_2$ from the treatment tanks at the Hamilton sewage treatment plant.

Because of their close proximity to each other, the SWARU and Hamilton STP atmospheric emissions are assumed to originate from the same source location.

A series of concentric circles was plotted around the source location, with radii of 1, 5, 10, 15 and 20 km. Homogeneous atmospheric conditions and transfer parameter values (P_{I1} for SWARU, P_{S1} for the sewage treatment plant and incinerator) were assumed to apply within the zones of 100 m - 1 km, 1-5 km, 5-10 km, 10-15 km and 15-20 km from the source term.

The population within each zone was estimated, based on a mean population density of 2,606/km^2 over the estimated 202 km^2 urbanized area of Hamilton-Burlington. Rural areas within the city boundaries of Burlington were not included in this estimation. The proportions, p, of the total populations of 525,000 found within each zone, i, are:

Zone	pi
100 m - 1 km	0.0156
1 - 5 km	0.152
5 - 10 km	0.400

10 - 15 km	0.336
15 - 20 km	0.0958

These pi values are used to weight the dispersion coefficients, P_{I1} and P_{S1}, for the calculation of collective doses.

The atmospheric dilution downwind of the source location is modelled through the estimation of P_{I1} and P_{S1} values, which represent atmospheric activities of radioisotopes at a given downwind location, (Bq/m^3) divided by the emission rate (Bq/s); thus P_{I1} and P_{S1} values have units of s/m^3.

The Canadian Standards Association (CSA, 1984) has provided a set of atmospheric dilution curves for standard atmospheric conditions representative of southern Canada. These coefficients were calculated based on a Gaussian plume formulation used to estimate average long-term concentrations of airborne contaminants at ground level downwind of continuous point sources, assuming a symmetric wind rose pattern. These dilution curves, representing dilution factors in s/m^3 at various downwind distances for selected emission heights, are reproduced in Figure A1. We recognize that this dispersion model is very simplistic. The wind rose pattern will in reality be skewed by the direction of the prevailing winds at Hamilton-Burlington. Also, the effects of Lake Ontario and the Niagara Escarpment on the local meteorology complicate the atmospheric dispersion characteristics in the study area. This simplification is justified as long as the estimated collective doses are low and relatively insensitive to source-term perturbation (see Appendix I - Sensitivity Analysis).

Population-weighted geometric mean atmospheric dilution coefficients (P_{I1} and P_{S1}) were determined for Hamilton-Burlington for calculating average atmospheric radioisotope concentrations. The geometric mean dilution coefficient, corresponding to the innermost and outermost limit for each zone, was calculated. The geometric mean P_{S1}/P_{I1} value for each zone was then weighted by the population assumed to live in that zone to determine a representative P_{S1}/P_{I1} for the entire population for each appropriate emission height:

$$P_{S1} \text{ or } P_{I1} = \sum_i (P_{S1(i)} \text{ or } P_{I1(i)})\ pi \qquad (9.1)$$

where, $P_{S1(i)}$ is the geometric mean P_{S1} calculated for zone i from SWARU emissions;
$P_{I1(i)}$ is the geometric mean P_{I1} calculated for zone i from STP emissions; and
p_i is the fraction of the total Hamilton-Burlington population living in zone i.

In the selection of P_{S1} and P_{I1} values from Figure A1, an emission height of 50 m was assumed to apply to both SWARU and the Hamilton STP. The SWARU stack is 50 m high while the STP stack is 42 m high. Adoption of an emission height of 50 m is conservative in both cases, since little or no plume rise is assumed. This has the effect of decreasing the estimated dilutions near the source, without significantly affecting dilutions at greater distances.

For releases of H-3 as HTO and C-14 as carbon dioxide from the STP lagoons, a similar set of calculations was carried out for an assumed emission height of 0 m.

The geometric mean, population weighted P_{S1}/P_{I1} dilution factors for 50 m and 0 m emission heights are calculated to be 4.6×10^{-8} and 5.5×10^{-7} $s \cdot m^{-3}$, respectively.

9.1.2 Average Atmospheric Concentrations for a Population Critical Group in Hamilton-Burlington

The average atmospheric concentrations of radioisotopes at the general population critical group location are those which are defined by the lowest dilution factors on the P_{S1}/P_{I1} dilation curves presented in Figure A1. For a 50 m emission height, the highest average P_{S1}/P_{I1} factor at the critical group location is conservatively assumed to be three times this value, or 1.1×10^{-6} $s \cdot m^{-3}$, to account for any skewness in the true wind rose pattern. The critical group location is about 500 m from the source location. For ground level releases at the 500 m location, the three times the P_{S1}/P_{I1} value is 1.2×10^{-5}.

9.2 External Dose from a Plume ($P(e)_{19}$)

The transfer parameter $P(e)_{19}$ relating the annual dose ($Sv \cdot a^{-1}$) to the annual average concentration of the radioisotope in air ($Bq \cdot m^{-3}$) is:

$$P(e)_{19} = \left[f_u + (1-f_u)\right] S \quad (DCF)_a \quad Sv \cdot a^{-1} \cdot Bq^{-1} \cdot m^3 \qquad (9.2)$$

where, f_u = occupancy factor, or fraction of time an individual spends outdoors exposed to the unshielded cloud;

S = shielding factor, or fraction of the "out-of-door" dose that is received indoors due to shielding by buildings;

$(DCF)_a$ = dose conversion factor for a semi-infinite cloud ($Sv \cdot a^{-1} \cdot Bq^{-1} \cdot m^3$).

Values of the shielding factor, S, for gamma radiation range from 0.6 for a masonry house and 0.9 for a wood frame house (Burson, 1977). For purposes of this report, the shielding factor for the Hamilton-Burlington population and for the population critical group is assumed to have an average value of 0.75. The occupancy factor, f_u, is assumed to be 0.2, since, the average citizen generally spends about 20% of his time outdoors (UNSCEAR, 1982).

Dose conversion factors, $(DCF)_a$, are given in Table B3 (Appendix B).

9.3 Deposition on Vegetated Soil (P_{13})

The transfer parameter for deposition on vegetated soil from a radioactive plume under steady-state conditions is:

$$P_{13} = v_g / \lambda_g \tag{9.3}$$

where v_g = deposition velocity ($m \cdot s^{-1}$);

λ_g = effective removal constant from the soil (s^{-1}).

The value of v_g for particulate radioisotopes is assumed to be 0.01 $m \cdot s^{-1}$. This value is sufficiently conservative to allow for the effects of both wet and dry deposition (Lush et al., 1985).

The removal constant from the soil, λ_g, is the result of by two processes - radioactive decay, characterized by the decay constant, λ_r, and environmental loss, characterized by a physical removal constant, λ_s. Thus, $\lambda_g = \lambda_r + \lambda_s$. The constant, λ_s, is taken to be $2.20 \times 10^{-10}\ s^{-1}$ for all radioisotopes, corresponding to an upper limit of the physical half-life for removal from the soil of about 100 years (CEC, 1979).

Values of the transfer parameter P_{13} used in this study are listed in Table A1 (Appendix A).

9.4 External Dose from Ground Deposits (P_{39})

The transfer parameter P_{39} is given by:

$$P_{39} = f_r (f_u + (1 - f_u) S_g) \cdot (DCF)_g \qquad (9.4)$$

where $(DCF)_g$ = dose conversion factor for ground deposits (smooth infinite plane) $(Sv \cdot a^{-1} \cdot Bq^{-1} \cdot m^2)$;

f_u = fraction of time an individual spends outdoors exposed to the ground deposit;

f_r = dose reduction factor to account for non-uniformity of the ground surface;

S_g = shielding factor, or fraction of the out-of-door dose received indoors, reduced due to shielding by buildings.

The value of f_u is 0.2 (Section 9.2) and the value of f_r is taken to be 0.7 (Burson, 1977). S_g is 0.4 for gamma radiation (Burson, 1977). This value is conservatively applied to mixed beta-gamma radiation (e.g., I-131). The value of P_{39} is, therefore, equal to:

$$(0.7)\ ((0.2) + (0.8)(0.4))\ (DCF)_g = 0.36\ (DCF)_g$$

The dose conversion factors $(DCF)_g$ are given in Table B4 (Appendix B).

9.5 Inhalation by Humans ($P(i)_{19}$)

The transfer parameter $P(i)_{19}$ relates the dose from inhalation of radioactive material $(Sv \cdot a^{-1})$ to the concentration in air $(Bq \cdot m^{-3})$.

$$P(i)_{19} = I \cdot (OF)_i \cdot (DCF)_i \quad Sv \cdot a^{-1} \cdot Bq^{-1} \cdot m^3 \qquad (9.5)$$

where I = inhalation rate $(m^3 \cdot a^{-1})$;

$(OF)_i$ = occupancy factor, or fraction of time an individual is exposed to the radioactive material in air;

$(DCF)_i$ = dose conversion factor for inhalation ($Sv \cdot Bq^{-1}$).

Values recommended by ICRP (1975) for I are $8.5 \times 10^3 m^3 \cdot a^{-1}$ for adults and $1.4 \times 10^3 m^3 \cdot a$ for infants.

For this assessment, we adopt a value for OF of 1 for the critical group residing near the emission source, and for the general population in the region.

SECTION 10

TRANSFER PARAMETERS FOR RELEASES TO WATERS

10.0 TRANSFER PARAMETERS FOR RELEASES TO WATER

10.1 Releases to Groundwater (P_{LO}

The only source for groundwater contamination is leachate from the landfill during filling. The two landfills have different characteristics. In Hamilton, leachate from the landfill travels vertically downward through unsaturated soil to groundwater and then to Red Hill Creek. In Burlington, leachate from the landfill is carried to a leachate collection system which is returned to the Burlington WWTP. Accordingly, Section 10.2 below describes transfer parameters from the Hamilton Landfill to Red Hill Creek while Section 10.3 describes transfer parameters from the Burlington landfill to the Burlington WWTP.

Detailed calculations of bulk landfill concentrations and leachate concentrations are given in Appendix B. A summary of the formulae is given herein. The formulae are:

$$C_{Landfill} = \frac{W_{DR}}{LFR} \qquad (10.1)$$

$$C_{Infilt} = \frac{(CR)\, C_{Landfill}}{ARV\,(1 + K_D \rho s/0.4)} \qquad (10.2)$$

if the original of the radioisotope is corrosion or decay from a solid form in the landfill,

or

$$C_{Infilt} = \frac{C_{Landfill}}{1 + K_D \rho s/0.1} \qquad (10.3)$$

if the origin of the radioisotope is rainfall indiced, ejection of soil moisture containing a radioisotope which is sorbed to the landfill solids. The resultant mass flow from the landfill to groundwater is:

$$\text{Mass flow from landfill} = (C_{infilt})\,(ARV) \qquad (10.4)$$

where, W_{DR} = loading (disposal) rate to the landfill (Bq/yr)

LFR = landfill filling rate ($1.8 \times 10^5 m^3/yr$ for Burlington; $6 \times 10^5 m^3/yr$ for Hamilton)

ARV = annual rainfall volume (m^3/yr)

K_D = linear distribution coefficient (mL/gm)

ρ_S = bulk solids density (gm/cc)

These formulae result in the following definition of a transfer parameter from landfill to groundwater

$$P_{LO} = \frac{C_{Infilt}}{W^1_{DR}} \tag{10.5}$$

where $W^1_{DR} = WDR/3.2 \times 10^7$ s/yr

10.2 Transfer from Groundwater to Surface Water (Hamilton; P_{02})

The annual loading to surface water (W_{RH}) from groundwater is

$$W_{RH} = f_G C_{Infilt} ARV \tag{10.6}$$

where f_G is the amount of attenuation due to the ground. Values for f_G are radioisotope specific and are discussed in Appendix D.

This results in the following value for Co (see Figure 10.1) entering Hamilton Harbour,

$$W_{RH} = Coq\,(1+\alpha)\,A_{HH} \tag{10.7}$$

Synthesis of the formulae results in the followng definition for $P_{0,2H}$ of

$$P_{0,2H} = f_G.ARV.\,(C/Co)_{HH}/(q\,(1+\alpha)\,A_{HH}) \tag{10.8}$$

where the symbols are defined above and $(C/Co)_{HH}$ is the ratio of the equilibrium concentration in Hamilton Harbour (C), to the average inflow concentration (Co), defined

10.5 Dispersion of Liquid Effluents

For calculation of surface water activities, Hamilton Harbour is taken as standard surface water body, because it is the waterbody routinely impacted by wastewater discharges and landfill effluents. The municipal water supply for Hamilton and Burlington is Lake Ontario but some use of Hamilton Harbour (fishing, recreation, irrigation) is possible. The transfer function description of Lake Ontario is dependent upon the pathway considered; for example, a plume model is appropriated for water intake and contaminated shoreline, on the other hand, either a plume model or a well mixed model may be appropriate for Lake Ontario fish. Accordingly, by referencing releases to Hamilton Harbour, the transfer function for particular pathways (irrigation, fish, water intake, etc.) includes the appropriate modelling description of Lake Ontario, as well, as geometric aspects concerning the point of withdrawal of water use.

10.5.1 Hamilton Harbour Model

The activity (C) of radioisotope in Hamilton Harbour due to inputs of radioisotopes (W(Bq/a) from wastewater treatment plants and Red Hill Creek is (Klapwijk and Snodgrass, 1984):

$$\frac{C}{Co} = \frac{q(1+\alpha)}{\lambda Z + q(1+\alpha) + gf} \qquad (10.12)$$

where, Co is the average inflow activity (Bq/m^3; = W/Q)

Q is the average annual flow rate from the Harbour

q is the hydraulic loading (q=Q/A = 15m/a)

A is the Harbour's surface area (m^2)

Z is the mean depth (13.6 m)

g is the settling rate of particles (25 m/a)

f is the fraction of radioisotope which is particulate

λ is the radioisotope decay rate (a^{-1})

α is the effect of lake/bay exchange upon washout (α=6)

W = radioisotope input from Red Hill Creek + Burlington WWTP + Hamilton WWTP (Bq/a)

The resulting ratio of C/Co is given in Table 10.1. The detailed calculations are given in Appendix D. Concentrations of radioisotopes in Hamilton Harbour are listed in Table 10.1.

10.5.2 Lake Ontario Model (Plume Model)

For mass flow from Hamilton Harbour to the WTP intake in Lake Ontario, it is assumed that the Harbour's discharge acts as a diffuser-like discharge described by the NUREG 1.113 (1977) nomograph. The nomograph is based upon typical lake conditions for the centre line concentration at 1 km and assuming an average current from the Harbour's point of discharge to the WTP intake of 10 cm/s. The nomograph gives the following relationship for the concentration at the WWTP intake,

$$C_{WTP} = (0.01)\, W_{LO} \exp - (K)\,(0.1) \qquad (10.13)$$

where, W_{LO} is the loading from the harbour to Lake Ontario in Bq/s.

The factor, 0.01, has units s/m^3 and gives units for C_{WTP} of Bq/m^3. The factor, 0.1 in the exponent represents the time of travel (in days) from the Harbour to the intake while the removal rate constant, K, has units of $days^{-1}$. Assuming that sorption and settling is negligible, then K is due only to radioactive decay.

Relating W_{LO} to W_H gives,

$$W_{LO} = \frac{C}{Co} W_H \qquad (10.14)$$

10.5.3 Biochemical Parameters in Hamilton Harbour Model

The fraction of a radioisotope which is particulate requires calibration. Its value, its basis of calibration, and the resultant value for C/Co are given in Table 10.1.

TABLE 10.1: CALCULATION OF C/Co FOR EACH RADIOISOTOPE IN HAMILTON HARBOUR

Radioisotope	f	K_D used for f	C/Co	Concentration ($Bq \cdot L^{-1}$)
Am-241	0.1*	10^4	0.97	1.5E-13
C-14	0	-	1.0	6.8E-4
Co-57	0.9+	-	0.82	7.4E-11
Cr-51	0.6+	-	0.42	4.4E-4
Ga-67	0.2**	-	0.092	2.0E-4
H-3	0**	-	1.0	4.6E-5
I-125	0**	-	1.0	1.3E-2
I-131	0**	-	1.0	3.6E-2
Ni-63	0*	-	1.0	4.5E-5
P-32	0.8++	-	0.84	1.1E-4
P-33	0.8++	-	-	-
Po-210	0.2**	-	0.78	1.4E-13
S-35	0**	-	0.73	4.2E-4
Se-75	.25+	-	0.3	-
Tc-99m	0**	-	0.0075	2.2E-3
Tl-201	0**	-	0.086	2.2E-3
Zn-65	.20+	-	0.25	2.3E-10

* Based upon K_D and suspended solids concentration of 10 mg/L

** Assumed

\+ Observations of Hesslein et al. (1980a,b)

++ Based upon observed partitioning between particulate P and soluble reactive P measurements in HH

10.5.4 Comparison of Lake Ontario Model to Well Mixed Model

Assuming that the lake is well mixed,

$$C_{WTP} = W_{LO}/Q_{STL}/(1 + K\tau_{LO}) \tag{10.15}$$

where, K = removal rate constant

Q_{STL} = St. Lawrence River Flow Rate (6600 m^3/s)

K = removal rate constant

τ_{LO} = detention time of Lake Ontario (7.9 yr)

These models are compared in Table 10.2, assuming that W_{LO} = 1 Bq/s for two different values of K; corresponding to half-lives of 1 day and 100 yr. The calculations indicate that the well mixed model is too conservative, justifying the use of the Plume Model.

10.5.5 Transfer Coefficient

The resultant overall transfer coefficient PO_{2H} is,

$$PO_{2H} = C/W^1 \tag{10.16}$$

where, the subscript of P, 2H is referenced as Hamilton Harbour surface water and W^1 is the total loading to Hamilton Harbour. Here, W^1 has units of Bq/s ($W^1 = W/3.2 \times 10^2$).

For individual point sources, the transfer coefficients are:

(i) P^B_{W2} for Burlington WWTP input

(ii) P^H_{W2} for Hamilton WWTP input

(iii) P^R_{W2} for Red Hill Creek

all have the same values as given above in Equation (10.16).

10.5.6 Transfer from Hamilton Harbour to City Drinking Water ($P_{2H,2C}$)

The transfer function describing radioactivity in drinking water is:

TABLE 10.2: COMPARISON OF PLUME MODEL AND WELL MIXED MODEL FOR C_{WTP}

	C_{WTP} for	
	$t_{1/2}$ = 1 day	$t_{1/2}$ = 100 yr
Plume Model (Eq 8.2)	.01	.01
Well Mixed (Eq 8.4)	10^{-7}	10^{-4}

$$P_{2H,2C} = \frac{C_{CITY}}{C_{HH}} \quad (10.17)$$

where C_{CITY} is the radioisotope activity in water delivered to the city (Bq/m^3),
C_{HH} is the radioisotope activity in Hamilton Harbour (Bq/m^3)

Evaluation of different models for Lake Ontario (Section 10.1) resulted in the following calculation formulae,

$$C_{CITY} = C_{WTP}(1-R) \quad (10.18)$$

$$C_{WTP} = (0.01)\, W_{LO} \exp -(te)(0.1) \quad (10.19)$$

$$W_{LO} = C_{HH}\, q\, (1+\alpha)\, A_{HH} \quad (10.20)$$

or

$$P_{2H,2C} = (0.01)\, q\, (1+\alpha)\, A_{HH} \exp(-K(0.1))(1-R)/3.2 \times 10^7 \quad (10.21)$$

where, A_{HH} = surface area of Hamilton Harbour ($2.1\ E7m^2$)
R = removal in WTP (decimal fraction)

and all other symbols are as defined in Section 10.1.

10.6 Drinking Water Intake by Humans ($P(i)_{29}$)

The transfer function describing drinking water intake to humans is,

$$P(i)_{2C,9} = \{\, k''_w \cdot I_w \cdot (DCF)_f \quad Sv \cdot a^{-1} \cdot Bq^{-1} \cdot L \quad (10.22)$$

where $(DCF)_f$ = dose conversion factor for intake by ingestion ($Sv \cdot Bq^{-1}$);
I_w = drinking water intake ($L \cdot a^{-1}$); and
k''_w = fraction of drinking water arising from the municipal water supply affected by radioisotope sources (assumed to be 1 in this case).

Dose conversion factors, $(DCF)_f$, for the ingestion pathway are given in Tables B1 and B2 (Appendix B). Water intake has been reviewed by the ICRP (1975), and the total intake by

reference man is 1.95 $L \cdot day^{-1}$, which is comprised of 0.3 $L \cdot day^{-1}$ of milk, 0.15 $L \cdot day^{-1}$ of tap water, and 1.5 $L \cdot day^{-1}$ from other sources (tea, coffee, juices, etc.) (ICRP, 1975). The value for infants (1-year old) is estimated to be 250 mL per day (Johnson and Dunford, 1983). Therefore, on an annual basis, the parameter I_w is 700 $L \cdot a^{-1}$ for adults and 90$L \cdot a^{-1}$ for infants.

10.7 Biological Concentrations in Hamilton Harbour Fish (P_{26})

The concentrations of radioisotopes in fish flesh are related to their concentrations in the water column by the relationship:

$$P_{26} = \frac{X_6}{X_2} = \frac{\text{Concentration in Fish Flesh } (Bq \cdot kg^{-1})}{\text{Concentration in Water } (Bq \cdot L^{-1})} \qquad (10.23)$$

The uptake of elements by fish involves accumulation from the water through the gills, absorption from food items, and absorption from ingested sediments. However, concentrations in sediments and food items are also functions of concentrations in the water column, and bioconcentration factors (P_{26} values) are typically expressed in terms of the concentration ratio given in Equation 10.23. P_{26} values used in this study are given in Table A.2 (Appendix A).

For the purpose of this assessment, we conservatively assume that fish consumed by the critical group reside in Hamilton Harbour and concentrations in fish flesh are governed by concentrations in the water at that location. In reality, few fishermen fish in Hamilton Harbour due to the poor water quality. Nonetheless, the MOE/MNR (1984) indicate that indigenous species in the Harbour are safe to eat, with few restrictions, in terms of contamination by heavy metals and organic contaminants.

10.8 Intake of Hamilton Harbour Fish by the Population Critical Group (P_{69})

It is unreasonable to assume that the general population of Hamilton-Burlington consumes any significant quantity of fish from Lake Ontario. If all of the annual commercial harvest of 3.24×10^5 kg for Lake Ontario (McKee and Rowsell, 1984) were consumed entirely by the approximately 6×10^6 residents of the Lake Ontario basin,

annual per capita consumption would average only 50 g or about 1% of the annual average Canadian adult consumption of freshwater fish, as given by Lush et al. (1985).

For the critical group in the Hamilton-Burlington population, the dose from the intake of fish from Hamilton Harbour is,

$$P_{69} = g_f \cdot I_f \cdot (DCF)_f \qquad Sv \cdot a^{-1} \cdot Bq^{-1} \cdot kg$$

where I_f = the rate of fish consumption ($kg \cdot a^{-1}$);

$(DCF)_f$ = the dose conversion factor for ingestion ($Sv \cdot Bq^{-1}$) (Table B1; Appendix B); and

g_f = fraction of consumed aquatic food arising from Hamilton Harbour

For this assessment, we assume that $I_f = 5.5\ kg \cdot a^{-1}$ for adults and $0.6\ kg \cdot a^{-1}$ for infants, given as the Canadian averages for freshwater fish consumption by Lush et al. (1985). The fraction arising from Hamilton Harbour, g_f, is conservatively assumed to be 1.

11.0 COLLECTIVE AND CRITICAL GROUP DOSE ESTIMATES

The following tables and discussion summarize the results of dosimetry modelling for the Hamilton-Burlington study area collective population (estimated at 525,000 people), for a critical group within the general population, and for occupational critical groups of workers within the waste management systems of these two cities. The derivation of source terms used in these calculations is presented in spreadsheets in Appendix G while the detailed dosimetry calculations for each radioisotope as well as the total dose estimates are presented in spreadsheets in Appendix H. The dose estimates are based on exposure pathways defined in Section 9.0 for atmospheric releases and Section 10.0 for releases to Hamilton Harbour.

At the start, it must be emphasized that the doses calculated in this study are all extremely small. In order to facilitate handling and graphical representation, the calculated doses are generally expressed as microsieverts (uSv) or sieverts multiplied by a negative exponential (E-6 = 10^{-6}). The maximum dose calculated for the conditions studied is the sewage sludge worker who is also a member of the general population critical group. This worker's maximum dose is 2.15E-6 Sv/a (= 2.15×10^{-6} Sv/a = 2.15 uSv/a = 0.00215 mSv/a). The regulated maximum dose to members of the general public is 5 mSv/a (= 5E-3 Sv/a = 5,000 uSv/a). Thus, the maximum calculated dose in this study is 0.043% of the permissible dose to members of the general population. This is illustrated on Figure 11.0.

11.1 Occupational Critical Groups of Municipal Waste Management Workers

The critical group concept is discussed in Section 6.1. The critical group of municipal waste management workers, as defined in Table 7.1, are those individuals which, through their daily work habits, stand the greatest potential for exposure to radioisotopes passing through the various municipal waste management and disposal systems. Their total dose is calculated as the committed dose at work plus the per caput dose for the general population. The highest possible dose occurs for an individual who is both a member of the critical group of municipal waste management workers and is also a member of the general population critical group. Dose calculations are summarized in Figures 11.1 to 11.5 for various municipal waste system critical groups.

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FIGURE 11.0

Maximum Calculated Dose Compared to AECB Regulated Maximum Dose for Members of the General Population

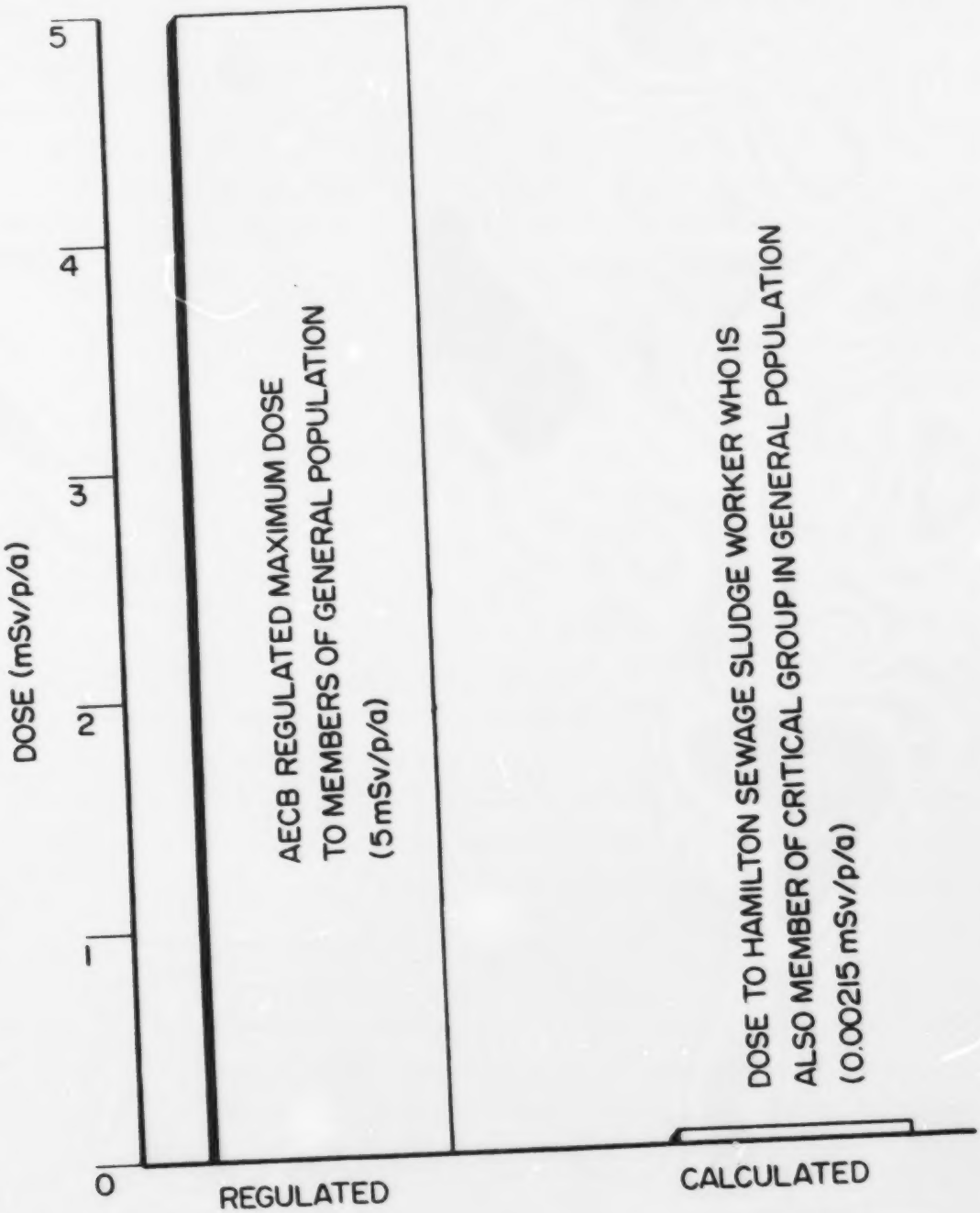


FIG. 11.1: HAMILTON STP WORKERS DOSES

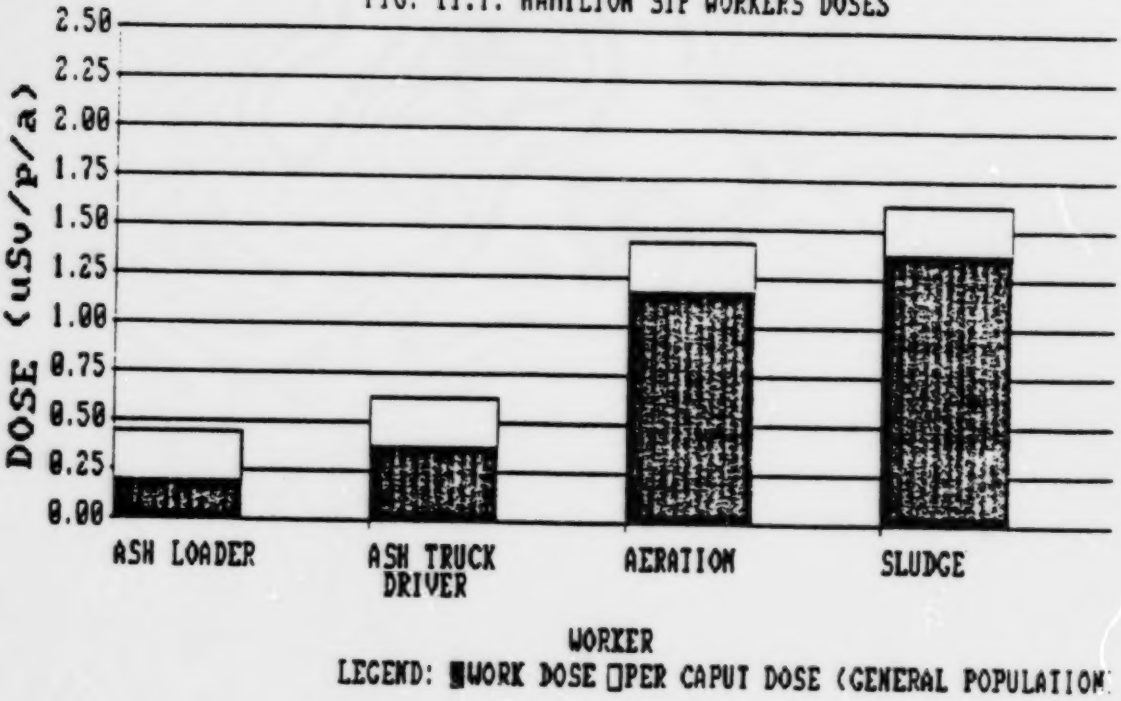


FIG. 11.2: HAMILTON LANDFILL & GARBAGE WORKER DOSES

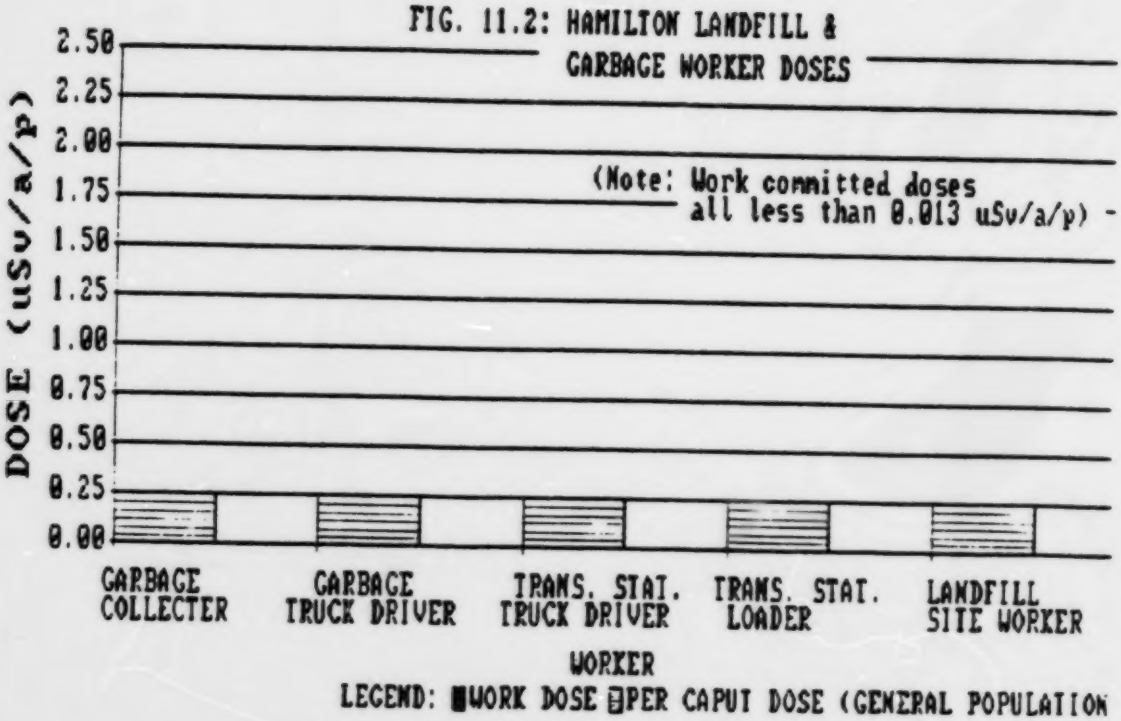
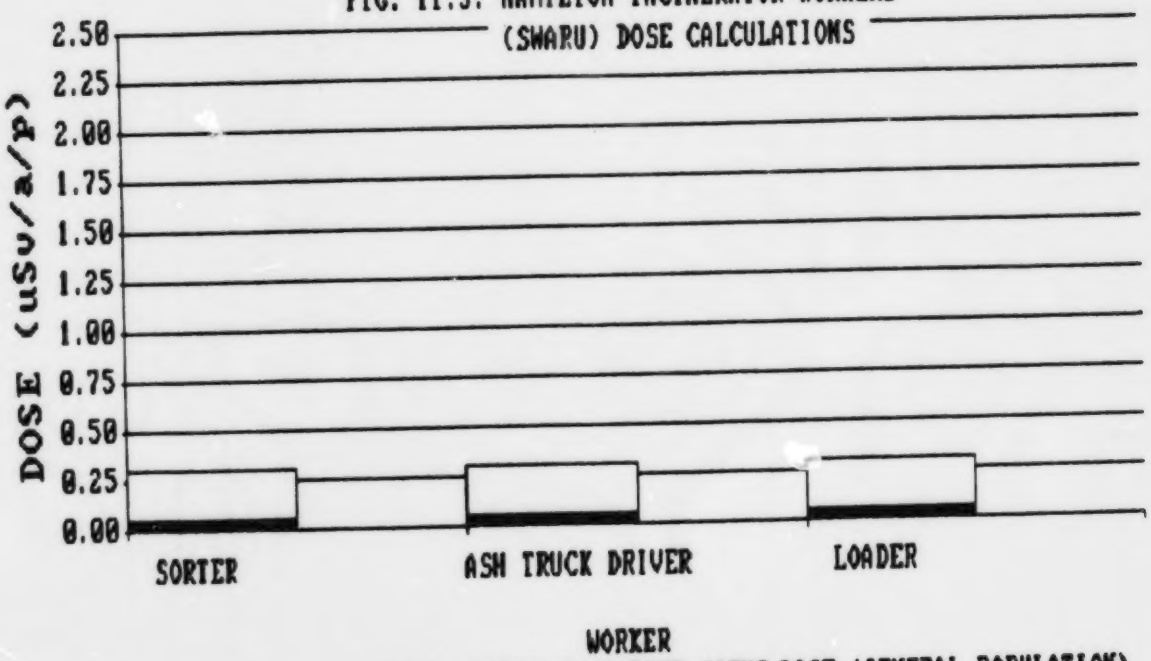


FIG. 11.3: HAMILTON INCINERATOR WORKERS (SWARU) DOSE CALCULATIONS



LEGEND: ■WORK DOSE □PER CAPUT DOSE (GENERAL POPULATION)

FIG. 11.4: BURLINGTON SOLID WASTE WORKER DOSE CALCULATIONS

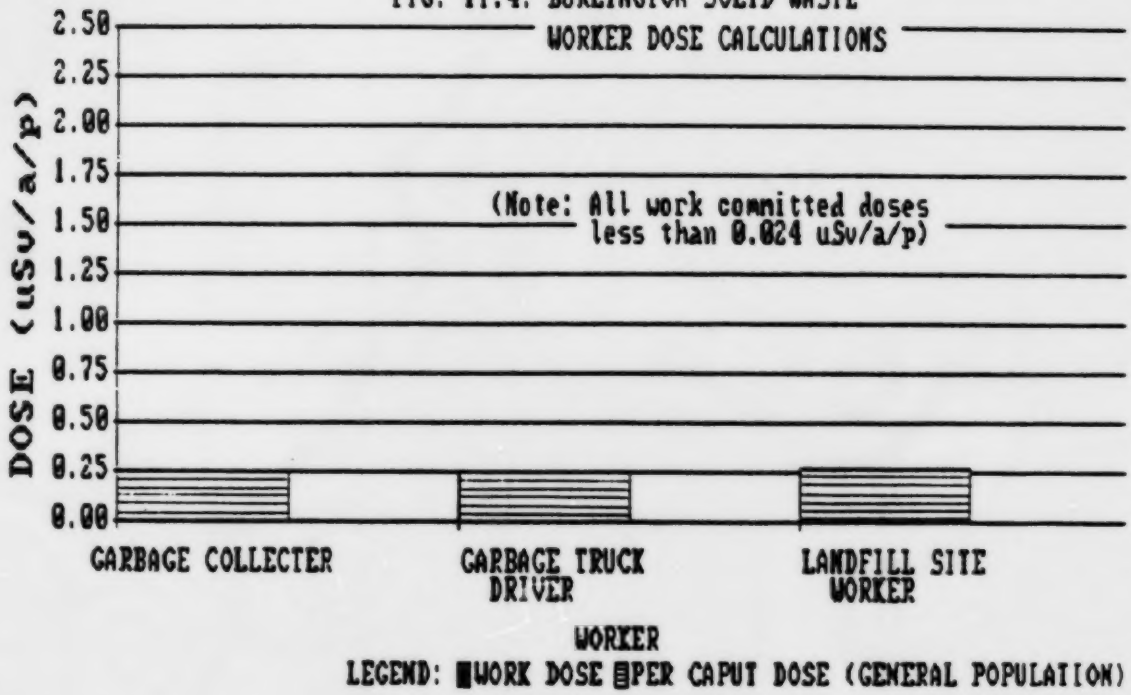
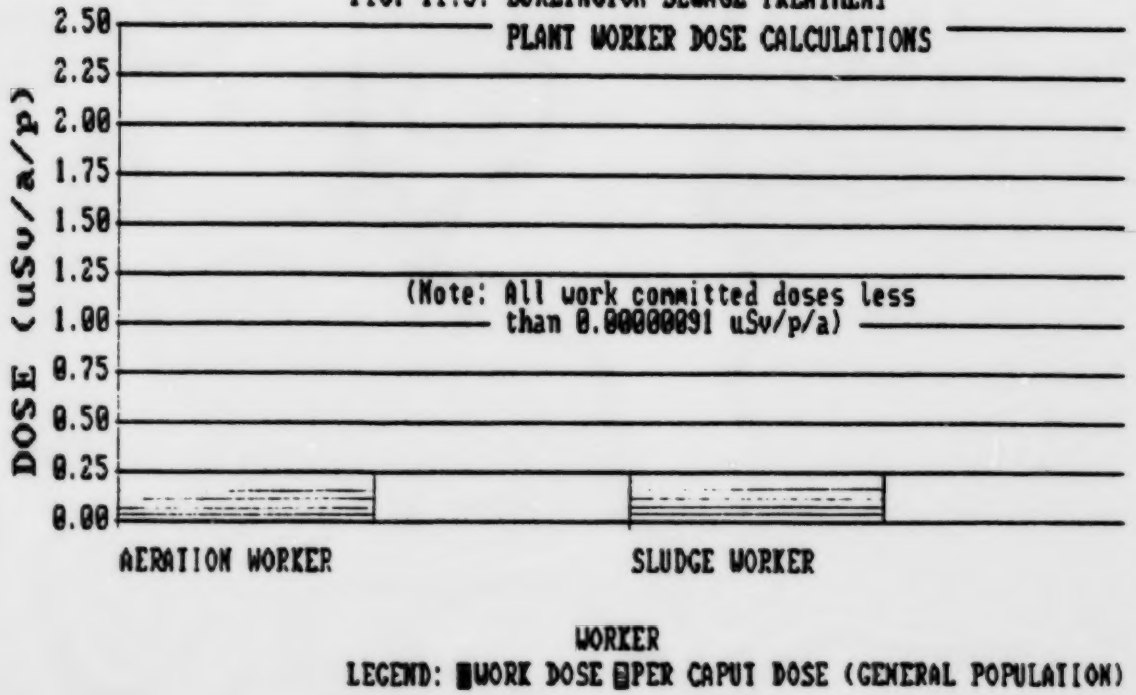


FIG. 11.5: BURLINGTON SEWAGE TREATMENT PLANT WORKER DOSE CALCULATIONS



Based on data in Table 7.1, eleven occupational critical groups were defined:

Solid Waste Workers		Liquid Waste
Landfill	Incinerator	Workers
Garbage Collectors*	Garbage Collectors*	Ash Loaders
Garbage Truck Drivers*	Garbage Truck Drivers*	Ash Truck Drivers
Transfer Station Drivers	Ash Truck Drivers	Aeration Workers
Landfill Workers	Sorters	Sludge Workers
	Loaders	

* Same workers assumed to service both sites.

Table 11.1 summarizes the dose estimates to these workers. Detailed dosimetry calculations are presented in Appendix H, Tables H-4 to H-14.

The highest dose estimates are for workers in the sewage treatment plant. The highest committed doses at work occur for sewage treatment plant workers ranging from 1.38E-6 Sv/a/p for the sludge worker to 2.08E-7 Sv/a/p for the ash loader. If the sludge worker was also a member of the general population critical group, this "worst-case" scenario would predict a dose of 2.15E-6 Sv/a/p. The dose estimates for solid waste management workers are all at least two orders of magnitude smaller than these. Dosimetry for worker critical group and the critical group in the general population is compared in Figure 11.6, with a comparison to AECB regulations in Figure 11.0.

11.2 Critical Group in the General Public

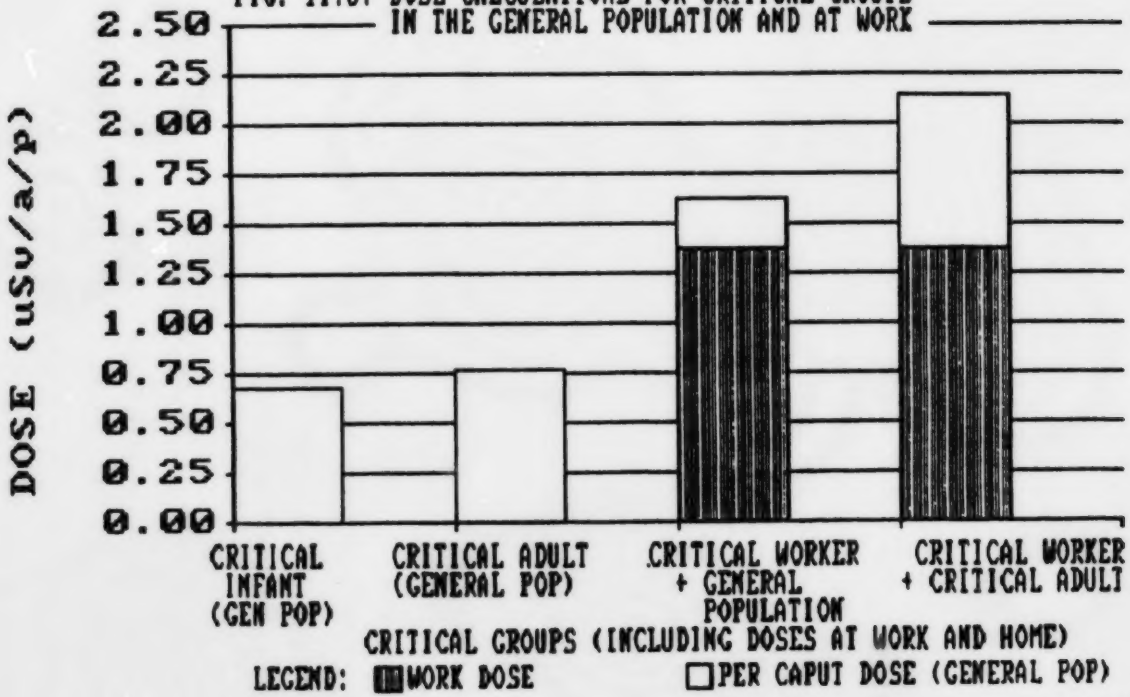
The general population critical group has been defined as living 1500 m downwind from the assumed combined point source location of the SWARU incinerator and the sewage treatment plant (Section 9.0). The Hamilton and Burlington STP's are conservatively assumed to be in the same location, while in reality they are separated by about 5 km. This critical group is also assumed to consume fish captured from Hamilton Harbour, at a rate estimated to be equivalent to the Canadian average for freshwater fish consumption (Section 10.0). This is also conservative in that Hamilton Harbour is not a sport or commercial fishing location and Lake Ontario fish will have a much lower exposure to the radioisotopes studied.

TABLE 11.1: SUMMARY OF TOTAL ANNUAL DOSE ESTIMATES FOR MUNICIPAL WORKER CRITICAL GROUPS (the sum of dose received at work and dose received (2.6E-7 Sv/a) as a member of the general population)

Occupation	Total Annual Dose Estimate (Sv/a)	
	Hamilton	Burlington
Sewage Treatment Plant:		
• Ash Loaders	4.68E-7	-
• Ash Truck Drivers	6.42E-7	-
• Aeration Workers	1.44E-6	2.60E-7*
• Sludge Workers	1.64E-6	2.60E-7
Solid Wastes:		
• Garbage Collectors	2.60E-7	2.70E-7
• Garbage Truck Drivers	2.60E-7	2.71E-7
• Landfill Site Workers	2.73E-7	2.84E-7
• Transfer Station Truck Drivers	2.60E-7	-
• Transfer Station Loaders	2.62E-7	-
• Incinerator Workers:		
- Sorters	3.15E-7	-
- Ash Truck Drivers	3.31E-7	-
- Loaders	3.16E-7	-

* Radiation dose commitments have been rounded to three significant figures. The base dose of 2.6×10^{-7} Sv is received as a member of the general population, while the increment above this value is due to occupational exposure. Dashes indicate a particular occupation does not exist in Burlington.

FIG. 11.6: DOSE CALCULATIONS FOR CRITICAL GROUPS IN THE GENERAL POPULATION AND AT WORK



The total doses estimated for the critical group in the general public are (Sv/a):

Group	Aquatic	Atmospheric	Total
Adults	6.31E-7	1.42E-7	7.73E-7
Infants	4.66E-7	2.13E-7	6.79E-7

For adult critical group in the general population, the dose estimates are about 82% from aquatic pathways and 18% atmospheric or terrestrial pathways (Figure 11.8). The dose estimate to infants is about 68% aquatic and 32% atmospheric or terrestrial. The major difference is due to adults consuming more fish. The collective dose is much more significant from aquatic sources than from air (Figure 11.7).

Detailed critical dose calculations for the general public are presented in Tables H-2 and H-3 in Appendix H.

11.3 Collective Dose Estimates

Collective dose estimates are detailed in Tables H-1 and H-3 of Appendix H. The total adult collective dose estimate is 1.37E-1 Sv/a. This results from an atmospheric pathway dose estimate of 3.12E-3 person Sv/a or 2.3% of the total, and an aquatic pathway dose estimate of 1.34E-1 person Sv/a or 97.7% of the total (Figure 11.7). The per caput dose estimate of 2.6E-7 Sv/a/person is based on a study area population estimate of 525,000 people. Per caput and critical group doses are compared in Figure 11.9.

The adult collective dose results primarily from three radioisotopes. Iodine-131 represents over 75% of the total collective dose, while I-125 represents about 22% of this total. Both are in aquatic pathways. The Am-241 represents almost 97% of the air pathway dose, but only 2.2% of the total collective dose. Radioisotope doses to various individuals are represented on Figure 11.10 and Table 11.2.

11.4 Comparison to Dose Estimates from Literature

Biancotto et al. (1982) modelled pathways and dosimetry of radioisotopes from sewages from two hospitals in Verona, Italy. They estimated critical group doses as follows:

FIG. 11.7: PER CAPUT DOSE (GENERAL POPULATION) BY PATHWAY

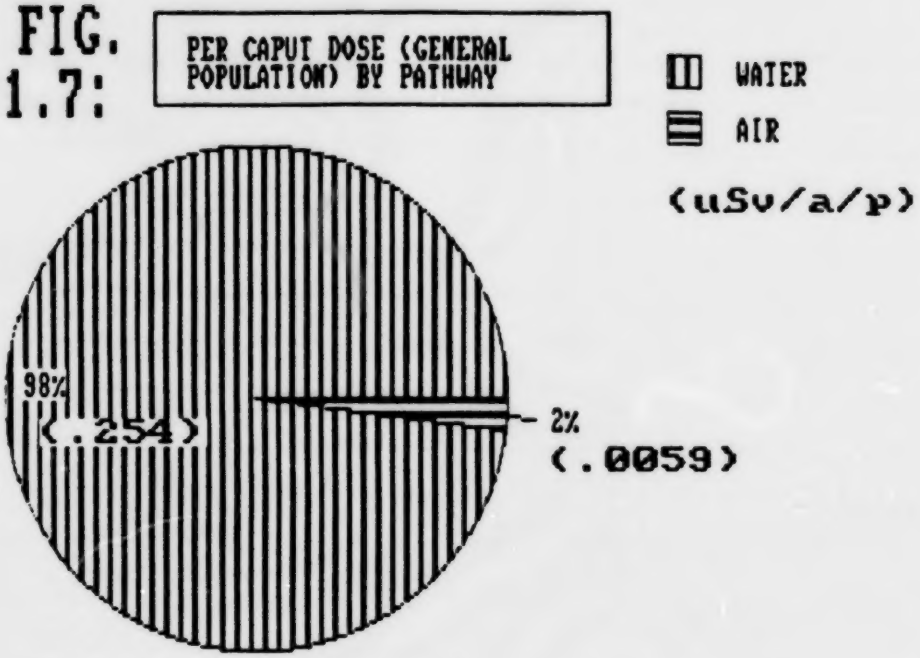


FIG. 11.8: DOSE TO CRITICAL GROUP IN THE GENERAL POPULATION BY PATHWAY

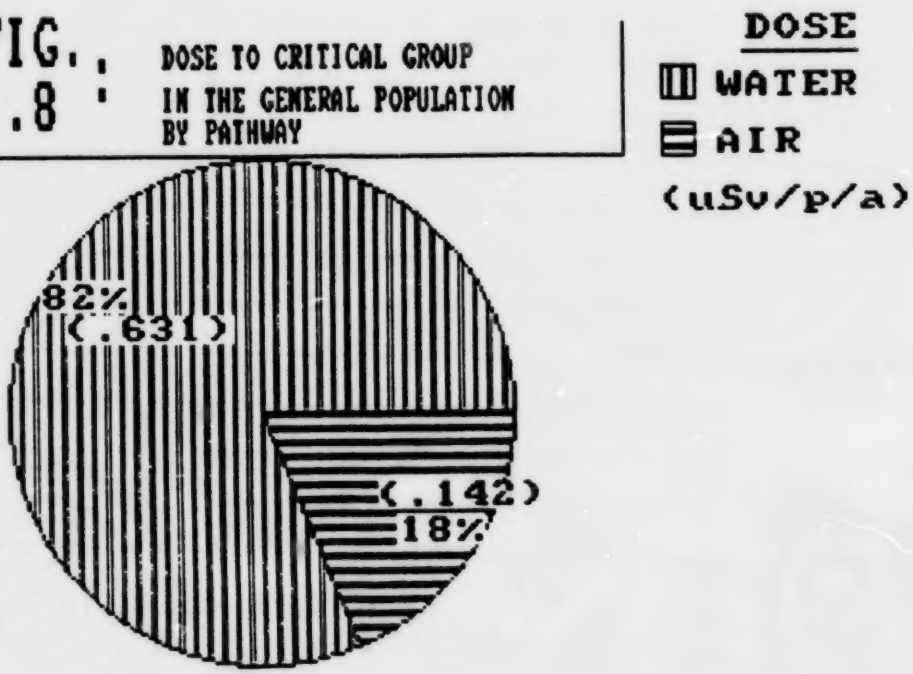


FIG. 11.9: CRITICAL GROUP vs PER CAPUT DOSES TO THE GENERAL POPULATION BY PATHWAY

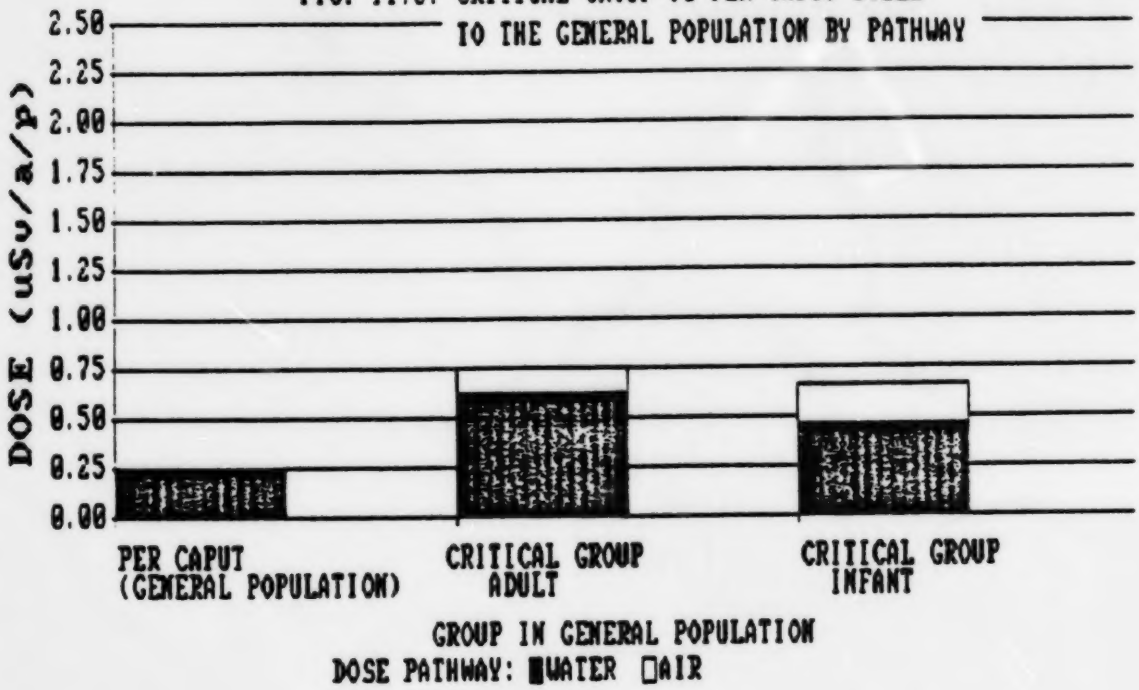


FIG. 11.10: DOSES BY RADIOISOTOPE TO SELECTED GROUPS

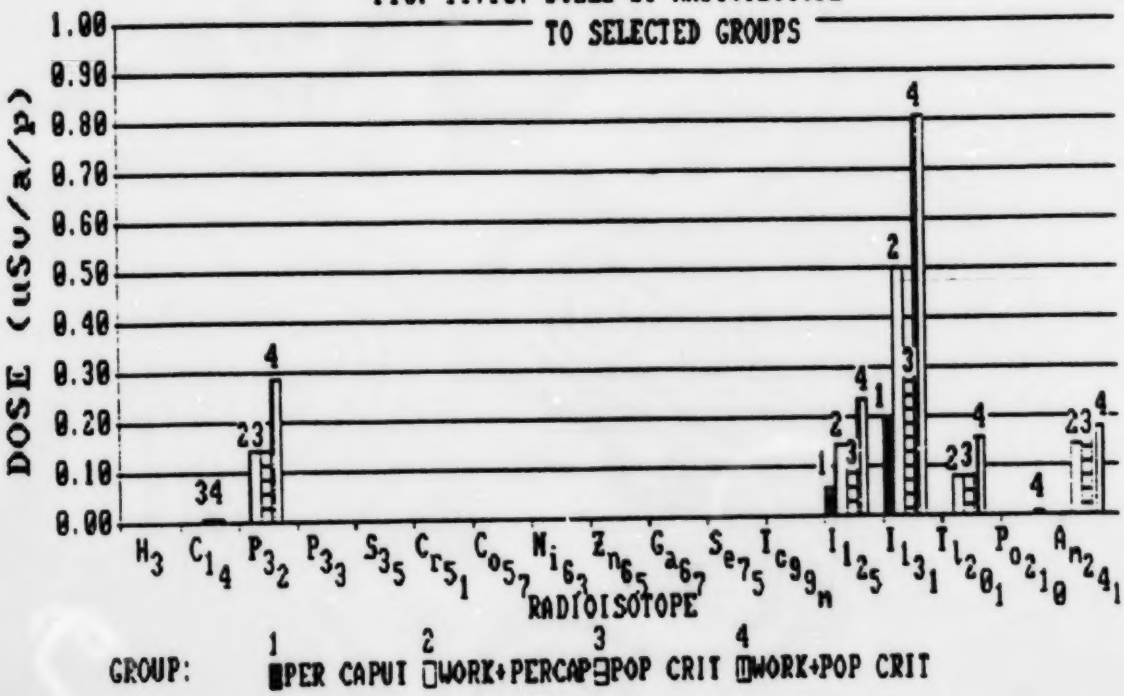


TABLE 11.2: COLLECTIVE GROUP PER CAPUT DOSE, HAMILTON SLUDGE WORKER CRITICAL GROUP DOSE AND GENERAL POPULATION CRITICAL GROUP DOSE FROM DIFFERENT RADIOISOTOPES

Radioisotope	Individual: Per Caput General Population	Individual: Sludge Worker + General Population	Critical Group in the General Population	Sludge Worker + Critical Group in General Population
H-3	3.00E-12	1.84E-9	6.23E-11	1.90E-9
C-14	1.62E-10	1.81E-10	9.25E-9	9.43E-9
P-32	3.37E-11	1.45E-7	1.45E-7	2.90-E-7
P-33	1.03E-17	3.24E-14	3.24E-14	6.48E-14
S-35	4.29E-11	2.30E-10	1.87E-10	4.17E-10
Cr-51	8.40E-13	2.05E-11	1.97E-11	4.02E-11
Co-57	1.47E-16	6.49E-16	5.02E-16	1.15E-15
Ni-63	8.08E-14	1.63E-12	1.55E-12	3.18E-12
Zn-65	7.26E-16	2.86E-14	2.79E-14	5.65E-14
Ga-67	1.96E-11	8.87E-11	6.91E-11	1.58E-10
Se-75	0	0	0	0
Tc-99m	1.58E-12	9.77E-12	7.19E-12	1.70E-11
I-125	5.79E-8	1.48E-7	9.05E-8	2.39E-7
I-131	1.96E-7	5.02E-7	3.06E-7	8.08E-7
Tl-201	6.91E-11	8.01E-8	8.01E-8	1.60E-7
Po-210	1.83E-10	4.57E-9	4.39E-9	8.96E-9
Am-241	5.75E-9	1.44E-7	1.38E-7	1.82E-7
TOTAL	2.60E-7	1.64E-6	7.73E-7	2.15E-6
PROPORTIONS:				
I	2.54E-7 (98%)	6.5E-7 (40%)	3.97E-7 (51%)	1.05E-6 (49%)
Am	5.75E-9 (2%)	1.44E-7 (9%)	1.38E-7 (18%)	1.82E-7 (8%)
P		1.45E-7 (9%)	1.45E-7 (19%)	2.90E-7 (13%)
Tl		8.01E-8 (5%)	8.01E-8 (10%)	1.60E-7 (7%)

Pathway	Dose (Sv/a)
Fish	1.4E-6
Vegetables	8.9E-9
Cereals	2.3E-9
Milk	4.0E-9
Other	4.7E-9
TOTAL	1.42E-6

Based on a population of 775,000 people, they calculated collective doses of:

Pathway	Dose (person-Sv/a)
Fish	24.0
Vegetables/Fruit	46.8
Cereals	14.7
Milk	25.4
Meat	17.5
Bathing	3.4E-4
Fishing	2.0E-2
TOTAL	128.4

This would represent a per caput dose estimate of 1.66E-4 which is inexplicably higher than the members of the critical group.

They also calculated the percentage of the total body dose equivalent from each radioisotope as follows:

Tl-201	0.9%
I-131	9.5%
I-125	19.3%
H-3	22.0%
C-14	14.3%
P-32	21.9%

In more directly comparable units, Wenk (1980) reported the average United States exposure to natural background radiation as 105 mrem/person/a (1.05 mSv/person/a). Of this total, 45 mrem/person/a (0.45 mSv/person/a) comes from cosmic radiation and 60 mrem/person/a (0.6 mSv/person/a) from gamma emitters. Wenk reports the natural background as approximately half of the overall background dose, with other sources including medical (0.85 mSv/person/a), technology (0.05 mSv/person/a), weapons testing (0.07 mSv/person/a) and nuclear power (0.003 mSv/person/a). These U.S. averages are probably comparable to the Hamilton/Burlington study area as the closest state, New York has close to the U.S. average with an estimated dose equivalent commitment per person per year of 1.1 mSv. He compares these to other sources such as dental x-rays (9 mSv/person/a), barium enema (80 mSv/person/a) and heart by-pass medication (450 mSv/person/a), as well as the NRC maximum radiation worker dose regulation of 50 mSv/person/a. The AECB guidelines are maximum doses of 50 mSv/person/a for Atomic Radiation Workers and 5 mSv/person/a for the general population.

UNSCEAR (1982) reports similar annual average per person doses of 2 mSv broken down as follows:

ESTIMATED PER CAPUT ANNUAL EFFECTIVE DOSE EQUIVALENTS FROM NATURAL SOURCES IN AREAS OF NORMAL BACKGROUND

	Annual Effective Dose Equivalent Commitment (uSv)		
Source of Irradiation	External Irradiation	Internal Irradiation	Total
COSMIC RAYS			
- Ionizing Component	280		280
- Neutron Component	21		21
COSMOGENIC RADIOISOTOPES		15	15
PRIMORDIAL RADIOISOTOPES			
- K40	120	180	300
- Rb-87		6	6

Source of Irradiation	Annual Effective Dose Equivalent (uSv) Commitment		
	External Irradiation	Internal Irradiation	Total
- U-238 Series:			
U-238, U-234		10	
Th-230		7	
Ra-226	90	7	1,044
Rn-222, Po-214		800	
Pb-210, Po-210		130	
- Th-232 Series:			
Th-232		3	
Ra-228, Ra-224	140	13	326
Rn-220, Tl-208		170	
TOTAL (rounded)	650	1,340	2,000

Figures 11.11 and 11.12 compare doses estimated in this study to natural and medical doses.

Preliminary Uncertainty Analysis

The main uncertainty in the calculated concentrations in this report are due to the assumed discharge rates of radioisotopes to the sewer system. The discharge rates have been estimated, assuming that the inventory licensed is used each year. Where knowledge is available that less than the inventory is used annually, the lesser number was used. The calculated concentrations are linearly related to the discharge rate; if the discharge rates are 50% for example, the calculated concentrations will similarly be too high. The next major source of uncertainty will be due to the partitioning assumed on

FIG.11.11: DOSES FROM NATURAL vs MUNICIPAL WASTE SOURCES

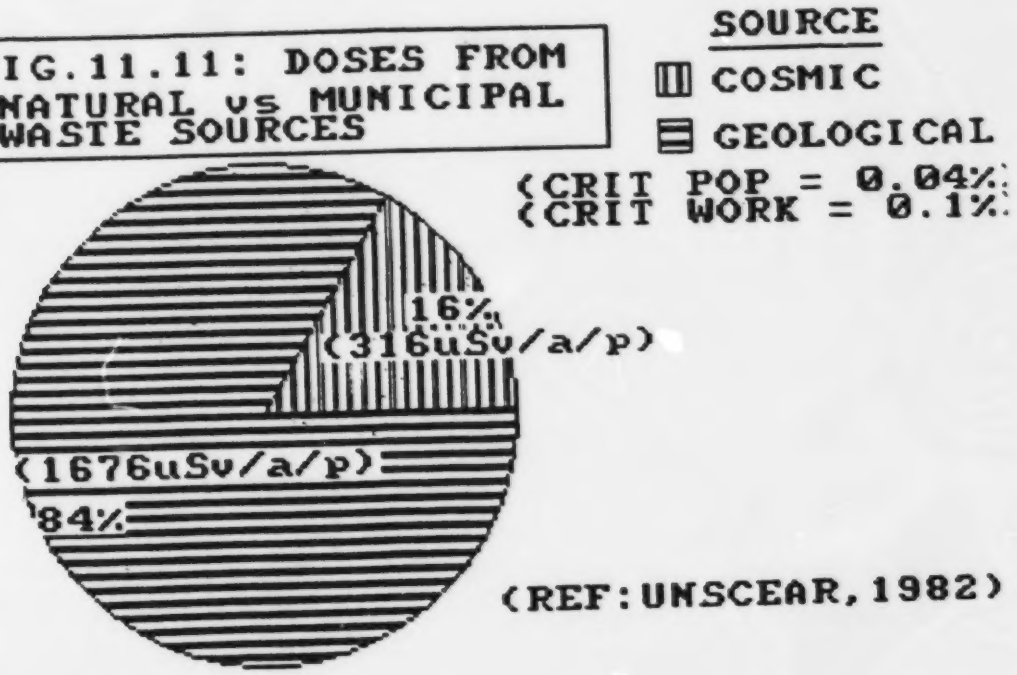
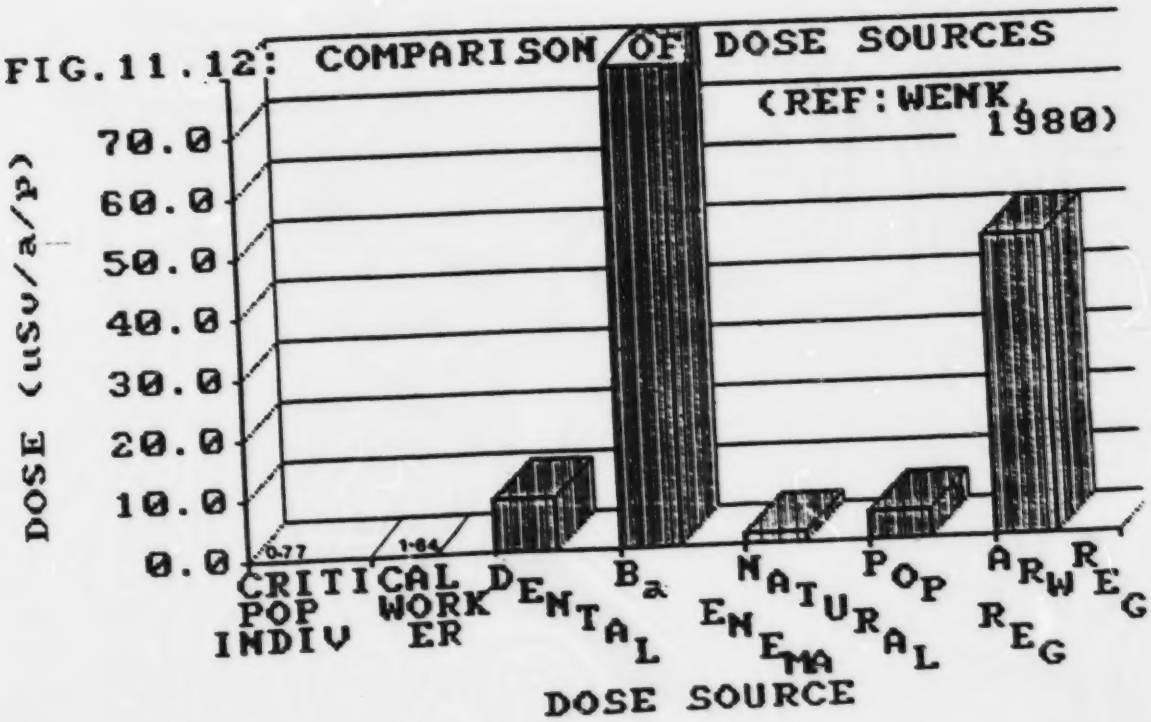


FIG.11.12: COMPARISON OF DOSE SOURCES



the wastewater treatment to sludge and surface water pathways. Within limits, this source of uncertainty will be substantively less compared to uncertainty associated with the discharge rates.

There are few measurements available to validate the calculated concentrations. Given the calculated levels of some radioisotopes in sludge, they should be detectable. It would be useful to make these measurements. This would validate the approach of using inventory information and relevant assumptions in municipal waste systems to calculate resultant concentrations.

Measurements are available for two radioisotopes. In one case, we have validation of the calculated concentration, while in the other we have a mystery. The calculations suggest that 3G Bq/yr Cr51 are discharged to the wastewater treatment plant of which 0.7 G Bq/yr goes to sludge and 2.3 G Bq/yr to the effluent. This compared favourably to measurements of 5.48 GBq/a discharged by the plant (Darham and Joshi, 1979). On the other hand, for I-131, the calculations indicate that 80 G Bq/yr are discharged by the plant, whereas measurements indicate that only 0.02 G Bq/yr are lost. (This is based upon 0.02 G Bq/yr in sludge and none being detectable in the water stream (Durham and Joshi, 1979).)

With the usage pattern and discharge of I-131, it is difficult to see that the loading to the WWTP would be much smaller than it is. But on the other hand, the calculated concentration on water (1 Bq/L) should be detectable. The calculated sludge concentration (2 Bq/kg dried solids) agrees reasonably well with the measured concentration (1.7 Bq/kg).

SECTION 12

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12.0 REFERENCES

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APPENDIX A

VALUES FOR TRANSFER PARAMETERS BETWEEN ENVIRONMENTAL COMPARTMENTS

FIGURE A.I

SYNOPSIS CARBON BUDGET FOR WASTEWATER TREATMENT PLANT

INFLUENT		100%
EFFLUENT ORGANIC C		5%
EFFLUENT & STRIPPED INORGANIC C		44%
SLUDGE		12%
DIGESTOR GAS	TOTAL	39%
	CH_4	14%
	CO_2 (g)	25%

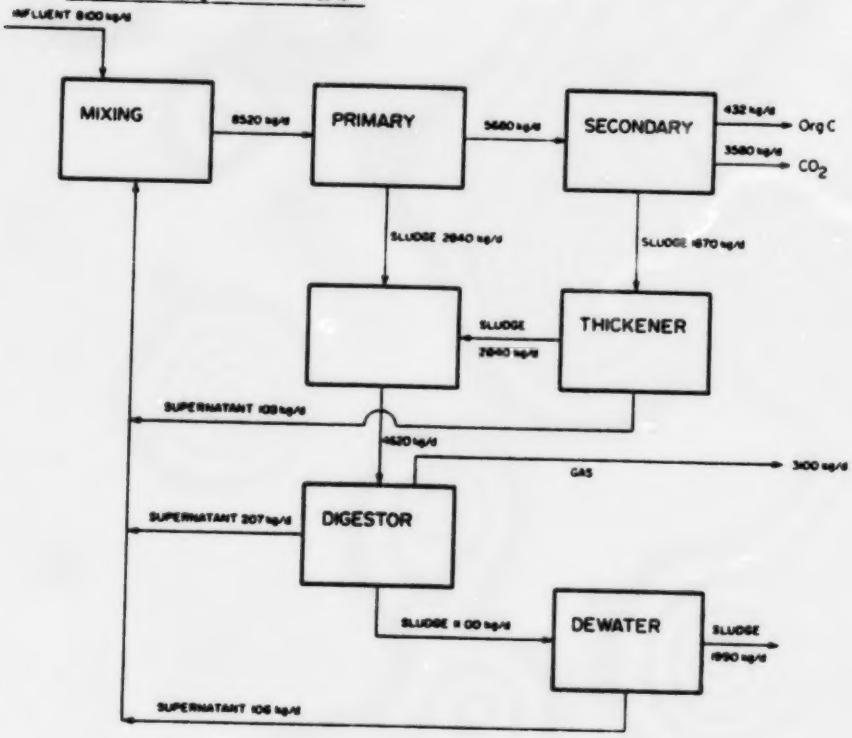


FIGURE A2: LONG-TERM AVERAGE DILUTION FACTORS FOR TYPICAL CANADIAN WEATHER AND UNIFORM WIND ROSE

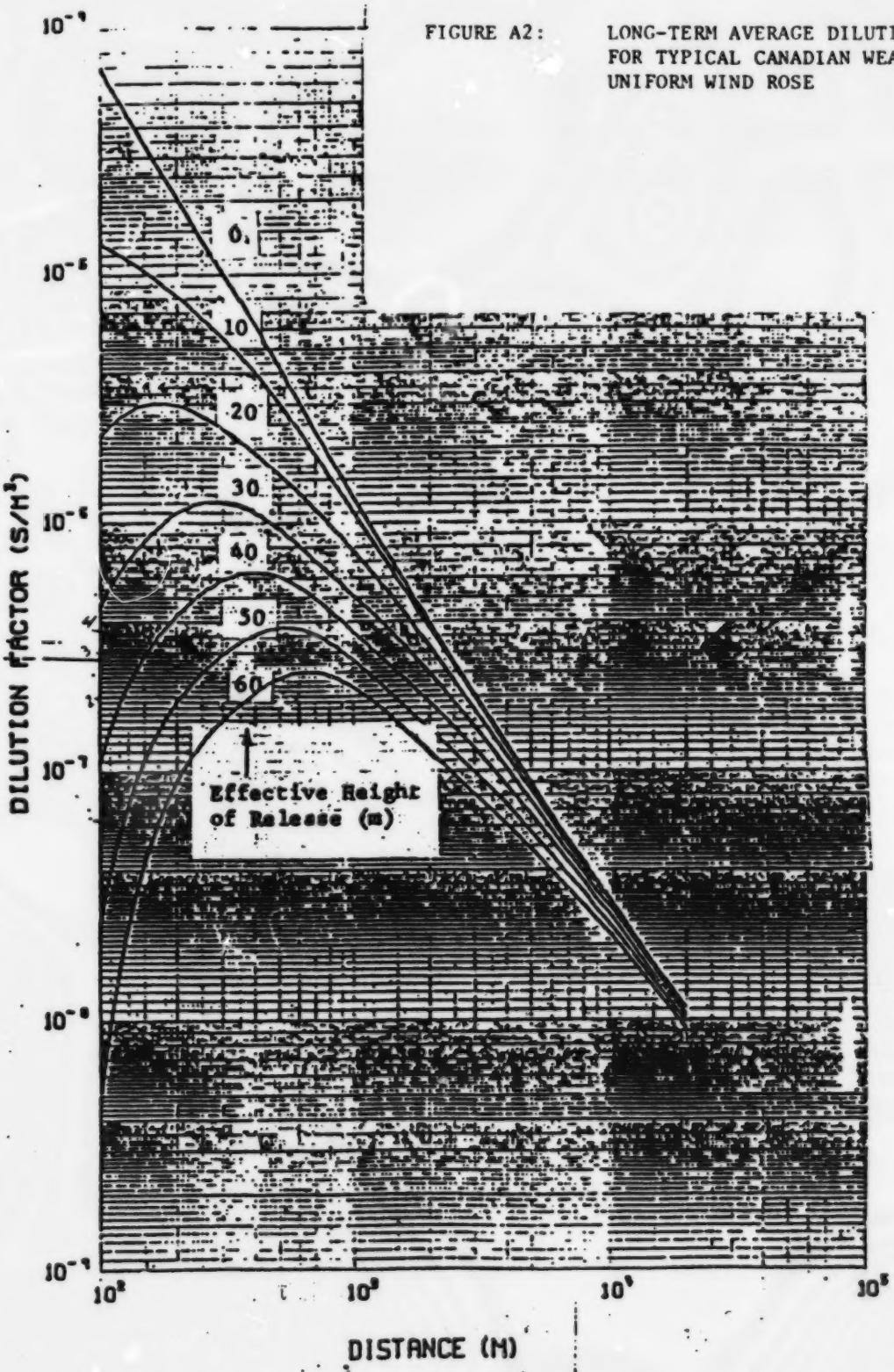


TABLE A1: TRANSFER PARAMETER P_{13} DEPOSITION OF AIRBORNE RADIOISOTOPES ON VEGETATED SOIL

Radioisotope	P_{13}(m)
H-3	-
C-14	-
P-32	1.78E4
P-33	1.79E4
S-35	1.09E5
Cr-51	3.47E4
Co-57	2.73E5
Ni-63	2.53E7
Zn-65	3.02E5
Ga-67	4.05E3
Se-75	1.49E5
Tc-99m	3.12E2
I-125	7.49E4
I-131	1.00E4
Tl-201	3.84E3
Po-210	1.71E5
Am-241	3.70E7

TABLE A2: TRANSFER PARAMETER P_{26} RADIOISOTOPE BIOCONCENTRATION FACTORS FOR FRESHWATER FISH CAUGHT IN HAMILTON HARBOUR

Radioisotope	$P_{13}(m)$
H	1
C	5,000
P	100,000
S	300
Cr	200
Co	100
Ni	40*
Zn	2,000
Ga	20+
Se	400*
Tc	30
I	50
Tl	100,000*
Po	50**
Am	30

* Data from U.S. EPA (1979)

** Lush et al., 1985

\+ our estimate, based on a typical bioconcentration factor of 16.6 in freshwater fish for Al, a chemically similar element, reported by Guthrie and Cherry (1976)

APPENDIX B

DOSE CONVERSION FACTORS

TABLE B1: COMMITTED EFFECTIVE DOSE EQUIVALENT CONVERSION FACTORS ($Sv \cdot Bq^{-1}$)

Radioisotopes	Inhalation Class+	Inhalation $(DCF)_i$ Adult	Inhalation $(DCF)_i$ Infant	f_1+	Ingestion $(DCF)_f$ Adult	Ingestion $(DCF)_f$ Infant
H-3 (HTO)	G	2.0E-11**	5.8E-11**	1	2.0E-11	5.8E-11
H-3 (HT)	G	2.4E-15	1.2E-14	-	-	-
C-14	G (CO_2)	5.2E-12	1.5E-11	1	5.2E-10	1.6E-9
P-32	W	4.4E-9	2.0E-8	0.8	2.3E-9	1.3E-8
P-33	W	6.8E-10	2.7E-9	0.8	2.4E-10	1.2E-9
S-35	W	7.8E-10	2.6E-9	0.8	-	4.9E-10
				0.1	2.0E-10	-
Cr-51	Y	1.0E-10	3.8E1-10	0.1	3.3E-11	6.9E-11
Co-57	Y	2.9E-9	8.2E-9	0.8	5.4E-10	1.7E-9
Ni-63	W	5.2E-10	1.6E-9	0.05	1.1E-10	2.2E-10
Zn-65	Y	5.7E-9	1.3E-8	0.5	4.0E-9	1.0E-8
Ga-67	W	1.5E-10	4.8E-10	0.001	1.9E-10	2.7E1-10
Se-75	W	2.1E-9	4.7E-9	0.8	2.6E-9	6.1E-9
Tc-99m	W	7.9E-12	4.1E-11	0.8	1.7E-11	8.1E-11
I-125*	G	9.3E-9	3.6E-8*	1	9.3E-9	3.6E-8
I-131*	G	1.1E-8	8.7E-8*	1	1.1E-8	8.7E-8
Tl-201	D	5.9E-11	2.7E-10	1	7.6E-11	3.2E-10
Po-210	W	2.5E-6	6.9E-6	0.1	5.3E-7	8.0E-7
Am-241*	W	1.3E-4	1.2E-3	0.005	6.0E-7	5.4E-6

* For these radionuclides, the non-stochastic dose limit for an organ may be limiting in both age groups and pathways. Therefore, a separate calculation using the organ dose conversion factors given in Table C2 should also be made.

** The inhalation dose conversion factors should be doubled to allow for HTO uptake via skin absorption.

\+ The chemical and physical form of a particulate radionuclide may be tied to a value of f_1 (the fraction reaching body fluids after entry into the gut) and, for the inhalation route, the lung retention class, i.e., the length of time the material is held in the lungs (W = slightly "soluble"; material remains in lungs for Weeks). Non-particulate gaseous forms are indicated by "G". The values listed correspond to the maximum value of the Dose Conversion Factor for each radionuclide.

TABLE B2: DOSE EQUIVALENT CONVERSION FACTORS, DCF_a FOR IMMERSION IN A CLOUD OF RADIOACTIVE MATERIAL $Sv \cdot a^{-1} \cdot Bq^{-1} \cdot m^3$

Radioisotope	Effective Dose+	Skin Dose**
H-3*	0.0***	0.0
C-14*	0.0	5.88E-9
P-32*	0.0	1.40E-6
P-33*	0.0	3.86E-8
S-35*	0.0	7.54E-9
Cr-51*	4.27E-8	5.54E-8
Co-57	1.72E-7	2.12E-7
Ni-63	0.0	0.0
Zn-65*	8.17E-7	1.10E-6
Ga-67	1.99E-7	2.55E-7
Se-75	5.34E-7	6.80E-8
Tc-99m	1.80E-7	2.25E-7
I-125*	1.50E-8	4.08E-8
I-131*	5.17E-7	9.39E-7
Tl-201	2.4E-8	3.0E-8
Po-210*	1.19E-11	1.62E-11
Am-241*	2.57E-8	3.81E-8

* Values for effective dose from Kocher (1983); values for skin dose from Kocher (1981).

\+ Effective dose excluding the weighted skin dose.

** Sum of the skin gamma dose factors and the electron dose factors at a depth of 70 um below the body surface.

TABLE B3: DOSE EQUIVALENT CONVERSION FACTORS, $(DCF)_g$, FOR EXPOSURE 1 M ABOVE A UNIFORMLY CONTAMINATED PLANE SURFACE ($Sv \cdot a^{-1} Bq^{-1} \cdot m^2$)

Radioisotope	Effective Dose+	Skin Dose**
H-3*	0.0	0.0
C-14*	0.0	0.0
P-32*	0.0	2.58E-7
P-33*	0.0	0.0
S-35*	0.0	0.0
Cr-51*	9.21E-10	1.22E-9
Co-57	3.87E-9	4.99E-9
Ni-63	0.0	0.0
Zn-65*	1.48E-8	2.01E-8
Ga-67	4.42E-9	5.93E-9
Se-75	1.16E-8	1.53E-8
Tc-99m	3.99E-9	4.92E-9
I-125*	6.68E-10	1.80E-9
I-131*	1.09E-8	2.01E-8
Tl-201	5.40E-10	7.00E-10
Po-210*	2.33E-13	3.15E-13
Am-241*	8.08E-10	1.73E-9

* Value for effective dose from Kocher (1983); values for skin dose from Kocher (1981).

\+ Effective dose excluding the weighted skin dose.

** Sum of the skin gamma dose factors and electron dose factors at a depth of 70 um below the body surface.

APPENDIX C

Sources of Radioisotopes
in
Municipal Waste Systems

APPENDIX C SOURCES OF RADIOISOTOPES IN MUNICIPAL WASTE SYSTEMS

Three main potential wastes of concern to the project are:

- liquid wastes disposed to the sewer,
- solid wastes disposed to landfill or incinerated, and
- liquid or solid wastes returned to Chalk River.

The three main sources are:

(i) household,
(ii) institutional (university and hospital), and
(iii) industrial.

Wastes defined to be considered in this project are these disposed of through municipal systems; hence industrial wastes disposed to their own landfills are neglected.

Hamilton, as a reference city, was selected for several reasons including:

- a typical city of less than 500,000 people,
- it has municipal, university, hospital sources, and
- it can be expected to use most major isotopes of concern.

Because receiving water/drinking water and economic units are common with Burlington, the municipal area considered is Burlington and Hamilton.

For the hospitals, and university, Dr. Harvey notes that we are rather fortunate in that the McMaster University Medical Centre Regional Radiopharmacy supplies virtually all the isotopes to local hospitals and so it is not necessary to canvas each individual hospital.

With respect to type of wastes from hospital, it is also useful to note that liquid wastes are the only significant wastes of concern to the project for Hamilton-Burlington. It is, in fact, rare for hospitals to generate any significant radiological activity in solid

waste. In hospitals, all in vivo uses and most in vitro uses of radioisotopes are in liquid form. In vivo uses require solution for injection into the body. Organic (in vitro) studies also require solution form. Wastes from in vivo uses are generated fron the leftover liquid solutions. In the laboratory, most liquid wastes go down the sink except those which are returned to Chalk River. The only solid wastes would be kleenex, lab coats and pipettes, etc.

The only other solid waste form from universities and hospitals would be sealed sources and reactor components. Under definitions of this project, sealed sources are assumed to be returned to Chalk River, except those which can credibly be determined to be exceptions. Two examples are Am-241 in smoke detectors and Ni-63 in electron capture detectors in gas chromatographs. Smoke detectors are routinely disposed in regular garbage. The sealed source in gas chromatographs (GC) should be returned to Chalk River. Recently at McMaster, one GC was returned to the radioisotope authorities because a technician noted the label on the GC. But because many do not appear to have such labels visible, the chance of all GC being disposed of properly has been judged to be small. Hence, it is assumed that one old GC's per year is disposed to landfill.

With respect to reactor components, all solid wastes (eg., Mo-) are returned to Chalk River; hence they are not considered on this project.

With respect to other communities, similar characteristics are generally expected. The only difference would be their method of waste handling, isotopes used, and travel distance to Chalk River. Hamilton is somewhat unique in that all radioisotopes used in the hospitals are either generated by the reactor or obtained by the Department of Health Physics and then supplied to the hospital. The University is also responsible for collecting all wastes and then shipping them to Chalk River. In addition, the University collects and ships sealed sources and other radioisotopes from local industry (eg., Stelco, Dofasco, etc.) to Chalk River.

In other communities, radioisotope waste collection may be more disparate. For Toronto, for example, one firm collects wastes from the Hospitals. For Guelph, university radioisotopes are kept separate at source; those which are short-lived are kept, allowed to decay and then disposed while those which are long-lived are sent to Chalk River. In Western Canada, economic pressures of transport will make it more difficult to ensure that all wastes are sent to Chalk River or other disposal facilities.

With respect to sealed sources, several sources expected are:

- gas chromatographs - Ni-63 - a few millicurie
  - Tritum - is losing favour
- anti static devices - Po-210
- thickness gauges - Sr-90; Cs-137; Am-241
- moisture probes - Am, Be, Californium-252, Cr; Ra-226
  - bulky, expensive; probably sent back to Chalk River

If sealed sources are sent to the dump, the main concern is the rate of corrosion, as most sealed sources are encapsulated in ceramic or metal. If ceramic, there is a chance that the ceramic would be imperfectly formed and allow release. If metalic, corrosion would be a significant agent causing release.

A synopsis of all radioisotopes licensed to be used in the Hamilton-Burlington area are given in Table 1. Their half-lives and some indication of their uses are also given. Reasons for selecting or rejecting the radioisotopes are indicated in the comment section. A final list of radioisotopes selected for the project and their possible chemistry are given in Table 2. The final list is, in part, based upon radioisotopes used in humans and of concern to the health physics literature (see Table 3).

TABLE C.1: SOURCE APPENDIX

Radioisotope	use	Licenced Bq	T 1/2	Include	Exclude	Comment
H-3	HUMVIV HUMVIT CALBR OP SCE CONSLD STALIM CHROMAT SUPPLR LT SCE OTHER	1.17E10 4.4E9 1.5E13 1.5E13 4.2E13 1.48E10 9.25E10 1.5E13 3.7E11 3.7E11	12.3 yr	X		University and Hospitals contribute ca 2GBq to sewer as liquid waste; nothing as solid waste. This estimate by Harvey proportioned to size of licence and known use. For wastewater analyses, ca 10 mCi/yr are spiked for other uses, 0.1 Ci are stored and used for spiking organic chemicals.
C-14	HUMVIV OP SCE HUMVIT CALIBR CHROMAT	4.5E9 3.0E9 6.0E8 3.0E8 4.0E6	5700 yr	X		Universities and Hospitals contribute ca 0.5 GBq to sewer as liquid waste; nothing as solid waste. This estimate by Harvey is proportional to size of licence and known use. About 6-10 mCi ^{14}C from BAC-TEC units is flushed down the sewers annually. For environmental samples, 25-50 uCi are stored. For organic chemical analyses, 100 mCi are stored.
C-11	HUMVIV	4E9	20 min		X	Short half-life. It is produced but not used.
Co-57	OP SCE CALIBR	1.39 3.0E9	220 d	X		1.1 mCi stored; used for internal standards in sediments and returned to Chalk River. AECB requested that we consider this one.
	HUMVIT HUMVIV CHROMAT SUPPLR	2.0E11 2.0E11 1.0E9 2.0E9			X	- only 2 x 10^{-6} GBq are used annually for HUMVIV uses - used as Mossbauer source - all are sealed
Co-58	HUMVIV	4.5E9	71 d		X	Same chemistry as Co-57. Nobody uses it in humans any more.
Cr-51	HUMVIV	5.9E9	27 d	X		Universities and Hospitals contribute ca 3GBq to sewer system annually; nothing as solid waste. This estimate, by Harvey is proportioned to size of licence and known use. Of the 57 mCi Cr-51 purchased by radiopharmacy only about 5 mCi ends up in the patients for excretion. The university is the largest user. Cr-51 was detected in Hamilton STP sludge and effluent, but not in that of Dundas by Durham and Joshi (1979).
Fe-55	ANALYZ	3.3E4	2.6 yr		X	
Fe-59	HUMVIV HUMVIT SUPPLR	4.74E9 4.0E8 4.0E8	45 d		X	Licenced, but not used to any extent (HUMVIV/VIT). A special check by Harvey indicates that it is used in about 3 patients per year 5 uCi each. For environmental samples about 1 mCi is stored for internal sediment standards and disposed to Chalk River.

TABLE C.1: SOURCE APPENDIX (cont'd)

Radioisotope	Use	Licenced Bq	T 1/2	Include	Exclude	Comment
P-33	Analytical	Not Given	14.4 d	X		100 uCi are stored. Most of this is injected into natural waterbodies.
Na-22	HUMVIV	1.0E9	2.6 yr		X	Licenced but not used.
Na-23	HUMVIV	4.0E8	Stable		X	Typo on licence (?) It is stable? Reject for consideration!
Na-24	HUMVIV	4.0E9	15 h		X	Licenced, but not used; also relatively short half-life.
K-42	HUMVIV	5.0E9	12.4 h		X	Licenced, but not used for humans.
O-15	HUMVIV	1.2E10	123 sec		X	Too short half-life
F-18	HUMVIV	4.0E9	110 min		X	Too short half-life
P-32	HUMVIV HUMVIT SUPPLR	2.1E10 4.0E9 4.0E9	14.2 d	X		Universities and Hospitals contribute ca 3GBq to sewer system; nothing as solid waste. This estimate, by Dr. Harvey, is proportioned to size of licence and known use.
S-35	HUMVIV OP SCE HUMVIT	4.0E8 1.0E9 4.0E7	88 d	X		Universities and Hospitals contribute ca 1.5 GBq to sewer system, nothing as solid waste. This estimate, by Dr. Harvey, is proportioned to size of licence and known use.
Ar-41	OTHER	1.1E11	110 min		X	
Ca-45	HUMVIT CALIBR HUMVIV	4.0E8 4.0E8 4.0E7	165 d		X	Nobody would put in a emitter, because you cannot see where it would go. It is a bone seeker.
Ca-47	HUMVIV	4.0E6	4.5 d		X	Same as Ca-45.
Co-60	CONSLD CALIBR OTHER SUPPLR	2.2E14 3.7E12 6.0E10 3.7E12	5.27 yr		X	Used as sealed source, generally.
Zn-65	Analysis	Not on AECB output	24.7 d	X		500 uCi are stored, used for internal standards on sediments and returned to Chalk River. This isotope will be tested incase it was accidently disposed to landfill.

TABLE C.1: SOURCE APPENDIX (cont'd)

Radioisotope	Use	Licenced Bq	T 1/2	Include	Exclude	Comment
Ni-63	CHROMAT OTHER HUMVIT CALIBR OP SCE SUPPLR	3.0E9 3.7E8 3.0E8 2.5E9 2.7E9 7.4E8	125 yr	X		No use except electron capture detector according to Dr. Harvey. Include because of possible disposal of GC's to dump. For environmental samples, 2.0 mCi is stored for use in sediments.
Ga-67	HUMVIV	2.9E10	77.9 hr	X		A special check by Harvey indicates that 40 mCi/wk are used. AECB requested that we consider this one.
Mn-56	OTHER	1.1E11	2.6 hr		X	Short half-life, very little used.
Se-75	HUMVIV HUMVIT SUPPLR	2.4E9 4.0E8 4.0E8	120 d	X		Not used for in vivo or in vitro studies. A small quantity was found in Dundas STP sludge, but not in Hamilton STP sludge. AECB requested that we consider this one.
Br-82	HUMVIV OTHER	4.0E8 1.1E11	36 h		X	Don't use generally for HUMVIV. Might use 1 mCi/yr in labelling studies of Br.
Kr-85	OP-SCE CALIBR OTHER SUPPLR SURPRO	3.7E12 3.7E12 1.85E12 3.7E12 1.1E4	10.76 yr		X	It is a gas.
Sr-85	HUMVIV	1.0E8	64 d		X	Not used since 1960's. Dr. Harvey did a special check on this isotope.
Sr-89	HUMVIV HUMVIT SUPPLR	4.0E9 4.0E9 4.0E9	51 d		X	Not used since 1960's. Dr. Harvey did a special check on this isotope.
Sr-90	BRATPY CALIBR SUPPLR	3.7E9 1.7E9 1.48E9	28 yr		X	Too toxic to use in people.
Mo-99	HUMVIV HUMVIT SUPPLR	2.0E11 2.0E11 2.0E11	67 hr		X	Used to generate Tc-99m in nuclear medicine but is not disposed to landfill or sewer. It is allowed to decay (6 min) and then returned to Chalk River.
Y-90	HUMVIV HUMVIT SUPPLR	5.6 E10 5.0E10 5.0E10	64 hr		X	Used in a colloidal form in humans. It seeks knee joints. Because it sticks to joints like glue, none of significance should get to the environment.

TABLE C.1: SOURCE APPENDIX (cont'd)

Radioisotope	Use	Licenced Bq	T 1/2	Include	Exclude	Comment
Tc-99m	HUMVIV	2.7E11	6 hr	X		One of prime tracers now used in HUMVIV studies because of its general transport capabilities, and short half-life. 100's of Curies, and generated annually. It is non-specific but tends to concentrate on tumors etc. On the other hand, in view of the six-hour half-life, this isotope does not warrant much consideration in spite of the fact that 878 Ci were delivered to Hospitals. Much of this decayed in situ or was not used; that which went into patients is retained to a large extent and so a relatively small fraction ended up in the sewers. It is retained in the body in colloidal form while part will be excreted. Estimates (by Harvey) suggest that 10-20% will be excreted within 1 hr as soon as the bladder is emptied, with fractional retention being up to 8 days. These figures will be interpreted to give an overall loading rate for the city sewer system.
Cd-109	ANALYZ	1.2E9	453 d		X	It is probably used mainly as a sealed source.
In-111	HUMVIV HUMVIT SUPPLR	2.1E10 4.0E9 4.0E9	2.891 d		X	It is increasingly being used as a replacement for Cr 51. It is used at a rate of 2 mCi/week. It gets tied up in interferon and stays in blood pool (platelets, red blood cells).
In-113 m	HUMVIV	3.7E9	99.8 min		X	Short-lived. It is used in ca 2 patients/month at rate of 500 uCi/patient. It gets tied up in interferon. Used for stomach emptying studies.
Sn-113	HUMVIT CALIBR	4.0E6 4.0E6	119 d		X	It is the parent of In-113. Sn-113 stays on resin column and In-113 m is milked off. Sn-113 is not used in the body itself.
I-123	HUMVIV SUPPLR HUMVIT	2.12E10 7.0E10 1.0E10	13.3 hr		X	Short-lived. Not used much at present. It will probably become the dominant form of iodine used in humans in the future.
I-125	HUMVIV HUMVIT CALIBR BRATPY SUPPLR ANALYZ	2.3E10 1.5E10 1.5E10 2.0E10 4.0E9 1.2E10	60.2 d	X		Used extensively as a fibrogen. If no blood clots form it is excreted in urine rapidly. They label ca 40 mC/week at radio-pharmacy. Approximately 750 mCi I-125 is injected into patients annually. Essentially all comes out during the body half-life. Approximately 5 mCi stored for labelling organics in laboratories not associated with hospital or university studies.
I-129	CALIBR	4.04E7	10^7 yr		X	Not known to be used for HUMVIT according to Dr. Harvey.

TABLE C.1: SOURCE APPENDIX (cont'd)

Radioisotope	Use	Licenced Bq	T 1/2	Include	Exclude	Comment
I-131	HUMVIV	7.4E10	8.05 d	X		Used in thyroid treatment. There is some question about how much gets to patients because more is purchased, and decays than is used in patients. It is estimated that the numbers given here are probably high and within a factor of 2, because another estimate places the usage at one-half of those given here. Approximately 2600 mCi I-131 is used in patients per year. In addition, another 80 mCi I-131 is used as iodohippurate, for a total of about 2700 mCi annually. In excess of 80% will be discharged by the patient, but the exact amount reaching the sewer will depend upon individual hospital practice. Some retain the urine excreted in the first 24 hours and set it aside to decay; others may flush it down the sewer. I-131 was detected in sludge of Hamilton and Dundas STP, but not in STP effluent by Joshi and Durban (1979).
Xe-127	HUMVIV SUPPLR	5.6E10 2.0E10	36.4 d		X	It is a gas dissolved in fluid, injected into blood. It should be expelled from the body from the lungs.
Ba-133	HUMVIT HUMVIV CALIBR	8.4E6 4.0E7 4.0E5	7.2 yr		X	Low quantity for HUMVIV. 250 uCi are stored for environmental samples. It is disposed to solid waste, being below 1% of schedule.
Xe-135	HUMVIV	3.7E9	9.14 hr		X	Gas, not used anymore because the half-life is too short.
Cs-137	PORGAG HUMVIT CALIBR CONSLD BRATPY SUPPLR OP SCE OTHER	7.2E9 4.4E7 2.3E13 7.4E13 5.0E9 5.9E12 5.9E12 8.3E9	30 yr		X	For HUMVIV it would not be used because it is non-specific. In the body, it has a 50-100 d half-time because people retain alot upon injection. For medical uses, it would be as an analytical standard. For other sources, it is used as standards in a Camera, as a sealed source. It also originates naturally. Cs-137 was detected in sludge of Hamilton and Dundas STP, and in Hamilton STP effluent, but not in Dundas STP effluent.
La-140	OTHER	110 G Bq	40.2 hr		X	It is not used to our knowledge.
Gd-153	HUMVIT CALIBR OP SCE SUPPLR	4.0E6 1.85E9 1.85E9 1.85E9	236 d		X	A special check was made by Harvey; none of it is used for in vitro purposes, except as a sealed source for standards probably in a Camera.
Yb-167	HUMVIV HUMVIT SUPPLR	5.0E9 4.0E9 4.0E9	31.8 d		X	Rare earth, used formerly in spinal fluid studies. Harvey did a special check. It is not used any more, being replaced for uses by Indium.
Tm-170	OP SCE CALIBR SUPPL	3.7E12 3.7E12 3.5E12	134 d		X	Used as a mossbauer source. It is a very weak gamma emitter.

TABLE C.1: SOURCE APPENDIX (cont'd)

Radioisotope	Use	Licenced Bq	T 1/2	Include	Exclude	Comment
Xe-133	HUMVIV	6.2E10	5.270 d		X	Used to check lung clearance. All should come out within 4 min, exiting as a gas from the body. No contribution to waste. Most heavily used isotope of Xe for HUMVIV.
Yb-169	HUMVIV	4.4E9	31 d		X	Same comment as for Yb-167.
Re-186	HUMVIV	46 Bq	3.7 d		X	A special check (Harvey) indicates that it has not been used for 1.5 yr. If it were used, it should essentially stay in the body, in arthritic joints at the rate of 1-3 mCi/treatment.
Ir-192	BRATPY SUPPLR	3.7E10 1.1E13	74.4 d		X	Standard (sealed) source for radiography.
Au-195	CALIBR HUMVIT	4.0E8 4.0E8	183 d		X	Passe. Sealed source for tumor. Au-198 is by far preferable and cheaper.
Au-198	HUMVIV BRATPY	1.14E10 3.7E10	2.69 d		X	A special check indicates that it is not used any more for liver studies. It is replaced by Tc-99m.
Hg-197	HUMVIV	3.0E9	65 hr		X	A special check was made by Harvey. It has not been used since the 1960's, being replaced by Tc-99m. It is not even available now.
Tl-201	HUMVIV	2.4E10	74 hr	X		It is a replacement for K in heart studies. It is used at rate of 30 mCi/wk and will leak out in urine. It was requested for consideration by AECB.
Hg-203	HUMVIV	1.0E9	47 d		X	It is used as a calibration (sealed) source. A special check was made by Harvey for HUMVIV; it has not been used since the 1960's.
Po-208	SUPPLR OPE SCE CALIBR	3.7E8 3.7E8 3.7E8	2.93 yr		X	1 uCi is stored for analysing fish, plant and sediment samples. This would be used over 3 years.
Po-210	STALIM SUPPLR OP SCE CALIBR	2.8E10 3.7E8 3.7E8 3.7E8	138 d	X		Used in anti-static devices. The usual supplier (3M in London) requests the user to return the device for disposal.
Ra-226	DEWPTR BRATPY SUPPLR CROMAT PORGAG HUMVIT	1.16E6 9.51E9 1.1E12 4.0E5 1.1E8 8.0E6	1620 yr		X	No HUMVIT uses were identified. 24 Bq are stored for environmental analyses. For liquid samples, typical samples analysed and their dipsoal gives 24 mCi/year to the wastewater treatment plant. For solids samples, many have 20,000 dpm/gm dry solids; these solids are returned to source after analysis.

TABLE C.1: SOURCE APPENDIX (cont'd)

Radioisotope	Use	Licenced Bq	T 1/2	Include	Exclude	Comment
Ra-226 cont'd	CALIBR OP SCE	2.31E8 1.11E12				Ra-226 was found in Hamilton and Dundas STP sludge (Joshi and Durham, 1979), but was not detected in effluent. Much of this may originate from natural sources (grit, etc.). AECB requested that we consider this one.
Th-228	SUPPLR OPE SCE CALIBR	1.89E11 1.89E11 1.89E11	1.91 yr		X	0.1 uCi stored for use in environmental samples. It was identified in Dundas and Hamilton sludge and Dundas STP effluent; this presumably originates from natural sources. AECB requested that we not consider this one.
Th-230	SUPPLR OPE SCE CALIBR	1.89E11 1.89E11 1.89E11	8×10^{4} gr		X	51 nCi - 9 uCi are stored for chemical analysis of environmental samples. At present, 1 uCi is stored. AECB requested that we not consider this one.
Th-232	Analytical	Not given in AECB output			X	Same as for Th-230. At present 0.1 uCi is stored.
Pa-233	SUPPLR CALIBR	3.0E10 3.0E10	27 d		X	Cannot identify use.
U-232	SUPPLR OP SCE	3.7E7 3.7E7	72 yr		X	Geology as a tracer; CCIW.
U-234	Analytical	Not given in AECB output			X	Analytical uses if not purified from U-238. AECB requested that we not consider this one.
U-235	SUPPLR OP SCE	7.4E6 7.4E6	7.1×10^{8} yr		X	AECB requested that we not consider this one.
U-238	SUPPLR OP SCE	2.6E10 1.85E6	4.5×10^{9} yr		X	AECB requested that we not consider this one.
Np-237	SUPPLR OP SCE CALIBR	7.4E5 7.4E5 7.4E5	2.2×10^{6} yr		X	Cannot identify use; possibly as a standard or tracer.
Pu-238	OTHER SUPPLR CALIBR OP SCE	3.7E9 1.86E11 1.86E11 1.86E11	86.4 y		X	Who- Amersham? Fabricate the pacemakers. Battery research - power source in satellites. OP SCE fabricator?
Pu-239	SUPPLR CALIBR OP SCE	2.22E6 4.85E6 2.22E6	4,300 ur		X	Cannot identify use, possibly as a standard or tracer.

TABLE C.1: SOURCE APPENDIX (cont'd)

Radioisotope	Use	Licenced Bq	T 1/2	Include	Exclude	Comment
Am-241	HUMVIT	4.0E5	458 yr	X		Smoke Detectors. Loading rate to environment will be based upon corrosion rate of detectors, assuming a useful life time of of 10 years per detector and that 75% of the smoke detectors have Am-241 in them.
	STALIM	1.78E6				
	SUPPLR	2.98E12				
	OP SCE	2.96E12				
	CALIB	2.98E12				
	ANALYZ	8.88E8				
	PORGAG	3.7E8				
Cm-242	SUPPLR	1.86E11	162.5 D		X	Cannot identify use.
	OP SCE	1.86E11				
	CALIBR	1.86E11				
Cf-252	SUPPLR	1.9E10	2.646 yr		X	Normally a sealed neutron source.
	OP SCE	1.9E10				
	CALIBR	1.9E10				

TABLE C2 ISOTOPES SELECTED AND PROBABLE CHEMISTRY

Radioisotope	Possible Form	Comment (use)
H-3	Tritiated Water	Labelling (Human)
C-14	Organic C Label	Labelling (Analytical/Human)
Co-57	Ionic	Vitamin B12 (Human; analytical)
Cr-51	Ionic: Chromate?	Radiopharmacy (Human)
P-32;P-33	Ionic PO_4^{3-}	Pathology (Human); environmental analysis
S-35	Organic S; some ionic SO_4^{2-}	Methionine is form of purchasing it
Zn-65	Ionic	Environmental Analysis
Ni-63	Alloy (to Ni^{2+} ?)	e capture detector; chemical analysis
Ga-67	Guess as an ion	Labelling (Human)
Se-75	Selenate ?	None used for in vivo or invitro studies
Tc-99m	Mostly as pertechnetate; some as organic form (colloid)	General Label (Human)
I-125	Fibrogen I	Injected as Fibrogen Released in Urine in ionic form
I-131	Iodide	Thyroid tmt (Human)
Tl-201	Ionic	Label (Human)
Po-210	encased in glass sphere	Anti static device
Am-241	Alloy; corrosion	Smoke Detectors

TABLE C3:

RADIOISOTOPES COMMON IN
HEALTH PHYSICS LITERATURE

LIST #1

MEDICAL INTERNAL RADIATION DOSE COMMITTEE

MIRD Committee
404 Church Avenue
Suite 15
MARYVILLE, TN 37801

Supplement 1, 1968, Journal of Nuclear Medicine

Pamphlet No. 1 - A Scheme for Absorbed-Dose Calculations for Biologically-Distributed Radionuclides (Revised 1976)
Pamphlet No. 2 - Energy Deposition in Water by Photons from Point Isotropic Sources
Pamphlet No. 3 - Absorbed Fractions for Photon Dosimetry

Supplement 2, 1969, Journal of Nuclear Medicine

Pamphlet No. 4 - Radionuclide Decay Schemes and Nuclear Parameters for Use in Radiation-Dose Estimation

Supplement 3, 1969, Journal of Nuclear Medicine

Pamphlet No. 5 - Estimates of Absorbed Fractions for Monoenergetic Photon Sources Uniformly Distributed in Various Organs of a Heterogeneous Phantom (Revised 1978).

Supplement 4, 1970, Journal of Nuclear Medicine

Pamphlet No. 6 - Radionuclide Decay Schemes and Nuclear Parameters for Use in Radiation Dose Estimation, Part 2.

Supplement 5, 1971, Journal of Nuclear Medicine

Pamphlet No. 7 - Distribution of Absorbed Dose Around Point Sources of Electrons and Beta Particles in Water and Other Media.

Pamphlet No. 8 - Absorbed Fractions for Small Volumes Containing Photon-Emitting Radioactivity.

Pamphlet No.10 - Radionculide Decay Schemes and Nuclear Parameters for Use in Radiation-Dose Estimation.

Pamphlet No.11 - "S" Absorbed Dose Per Unit Cumulated Activity for Selected Radionculides and Organs.

Pamphlet No.12 - Kinetic Models for Absorbed Dose Calculations.

Pamphlet No.13 - Specific Absorbed Fractions for Photon Sources Uniformly Distributed in the Heart Chambers and Heart Wall of a Heterogeneous Phantom.

MIRD Dose Estimate Reports - Journal of Nuclear Medicine

No. 1 - Summary of Current Radiation Dose Estimates to Humans from ^{75}Se-L-Selenomethionine - 1973.

No. 2 - Summary of Current Radiation Dose Estimates to Humans from ^{66}Ga-, ^{67}Ga-, ^{68}Ga- and ^{72}Ga-citrate - 1973.

No. 3 - Summary of Current Radiation Dose Estimates to Humans with Various Liver Conditions from ^{99m}Tc-sulfur colloid - 1975.

No. 4 - Summary of Current Radiation Dose Estimates to Humans with Various Liver Conditions from ^{198}Au-colloidal Gold - 1975.

No. 5 - Summary of Current Radiation Dose Estimates to Humans from ^{123}I, ^{124}I, ^{125}I, ^{126}I, ^{130}I, ^{131}I and ^{132}I as Sodium Iodide - 1975.

No. 6 - Summary of Current Radiation Dose Estimates to Humans from ^{197}Hg- and ^{203}Hg-labelled Chlormerodrin - 1975.

No. 7 - Summary of Current Radiation Does Estimates to Humans from ^{123}I, ^{124}I, ^{126}I, ^{130}I and ^{132}I as Sodium Rose Bengal - 1975.

No. 8 - Summary of Current Radiation Dose Estimates to Normal Humans from ^{99m}Tc as Sodium Pertechnetate - 1976.

No. 9 - Estimates of Radiation Absorbed Doses from Radioxenons in Lung Imaging - 1980.

No. 10 - Radiation Absorbed Dose from Albumin Microspheres Labelled with Technetium-99m - 1982.

No. 11 - Radiation Absorbed Doses from Iron-52, Iron-55 and Iron-59 Used to Study Ferrokinetics - 1983.

APPENDIX D

Calculation Assumptions
Source and Water Pathways

APPENDIX D Calculation Assumptions; Source and Water Pathways

D.1 Liquid and Solids Waste Calculations

1. Am-241

(a) Liquid Disposal

- None

(b) Solid Waste Disposal

- Source Assumptions
  - 230,000 Smoke detectors are in Hamilton-Burlington area (documentation C. Hostovsky).
  - useful lifetime is 10 years; 75% of detectors have Am-241
  - activity levels: 1 uCi/detector
  - disposal to solid waste = (230,000)(0.1)(0.75)(1)/27.1

    = 0.64GBq/yr

- Partitioning Assumptions to Solid Waste
  - Based upon number of people, Am-241 disposed to:

incinerator	.56
landfill without underdrain	.19
landfill with underdrain	.21
apt incinerator	.04

- Incineration Assumptions. Based upon NUREG/CR-1156; (pg. 3.34 discussion), assumptions are:
  - 1% of Am-241 in smoke detector is lost in incineration, leaving 99% to be landfilled.
  - Incinerator smoke detectors lose 10% of their initial activity in first year after disposal in landfill.
  - Data for loss rates of remainder of initial activity is not given in NUREG/CR-1156.

- Landfill Assumptions
  - Non incinerated smoke detectors lose 0.01 percent of source activity in one year (NUREG/CR-1156, pp. 3-36). This data is based upon an immersion test in a corrosive SO_2 environment. Leaching occurs due to corrosion of its silver backing.
  - Assume same loss rate for incinerated smoke detectors after first year.

- Adsorption Characteristics
  - Assume Am-241 can be described by linear distribution coefficient concept.
  - NUREG/CR-1156, (pp 3-34) indicates that migration is dependent upon soil pH. Several values for soil retention in (presumably) unsaturated media are given. One value indicates that the ratio of solution movement (V) to Am movement (Vc) is of the order of 10^4.
  - Assuming that the Solution-Am movement ratio describes the retardation concept (Freeze and Cherry, 1980).

$$\frac{V}{Vc} = 10^4 = 1 + 4\ Kd$$

  - The coefficient in front of Kd is for a soil with dry bulk density of ca 1.6 and a porosity of 0.4.
  - This gives a value for Kd for Am-241 of approximately 3000. The uncertainty associated with this value is of the order of 100% or more.

- Landfill Corrosion Rate (First Year)

  (a) Hamilton

Incinerator = 0.64 G Bq/yr x 0.56 x 0.99 x 0.1 in.	= 0.035	G Bq/yr
Ash Incinerator = 0.64 x 0.04 x 0.99 x 0.1	= 0.0025	G Bq/yr
Landfill Direct = 0.64 x 0.19 x 1.0 x 0.0001	= 0.00001	G Bq/yr
	0.038	G Bq/yr

(b) Burlington

- Landfill Direct = 0.64 x 0.21 x 1.0 x .0001 = 0.000013 G Bq/yr

- Landfill Export Rate (see sample calculations, Solid Waste Section)
  (a) Hamilton Landfill to Red Hill Cr = 0.3 Bq/yr
  (b) Burlington landfill to STP = 1 Bq/yr

- STP Partitioning
  - Am-241 has high adsorption characteristics (K_D = several thousand)
  - STP Removal of suspended solids = 95%
  - Assume 5% of Solids in effluent and 95% back to Landfill
  - Calculations give: .05 Bq/yr to HH
    .95 Bq/yr back to landfill
  - Neglect effect of landfill disposal upon landfill concentration

- Lake
  - HH Partitioning to WTP
  - Using 10 mg/L SS and assuming Kd in water column = 10^4, f=0.1

$$\frac{C_{HH}}{C_o} = \frac{q\ (1 + \alpha)}{k\ Z + q\ (1 + \alpha) + gf} = \frac{105}{0 + 105 + 2.5} = 0.97$$

  - Flux from Harbour = 0.85 q (1 +) C_o
    = (0.97)(0.3 + 0.05) = 0.3 Bq yr
    = 10^{-8} Bq/s
  - C at WTP Intake
    C = .01 W $\frac{(Bq)}{}$ exp (-)(0.1d)
    = (.01)(10^{-8})
    = 10^{-10} Bq/m^3

- Flux to WTP
  - Assume 90% removal in WTP by Coagulation Precipitation
  - Concentration to City = (0.1)(10^{-10}) = 10^{-11} Bq/m^3

2. C-14

(a) Liquid Disposal

- 0.5 G Bq are released by university and hospital units/yr.
- 4 G Bq are stored for use in labelling organics in analytical, chemical research.
- Assuming 50% of stored C-14 is used annually, loading to sewer system is 2.5 G Bq/yr.

- Sewer System Calculations
  - Hamilton
    - Assuming 0.5d residence time in Hamilton sewer sytem and decay rate of 0.1 hr^{-1}, loading to Hamilton sewer system of 0.5 G Bq/yr decreases to WWTP loading of (0.5) exp (-(0.1)(12)) or 0.15 G Bq/yr.

  - Burlington
    - Assuming 30 min. residence time in Burlington sewer system and biological decay rate of organic C of 0.1 hr^{-1}, loading to Burlington STP is:

      (2.0 G Bq/yr) exp ((-0.1 (0.5))
      = 1.9 G Bq/yr

    - Assume decay fraction are converted to CO_2 and remain in water.

- WWTP Aspects
  - Carbon budget for biodegradable C entering a WWTP are given in Figure C.1. This is based upon a design example from Metcalf and Eddy (1979).
  - Assume that all C-14 entering WWTP is organic and that it is partitioned the same as the biogradable C budget.

    - Hamilton Organic C Budget

Influent	0.15 G Bq/yr
Effluent Organic	0.0075 G Bq/yr
Effluent Inorganic	0.066 G Bq/yr
Total Effluent	0.074 G Bq/yr

Gas*	0.058 G Bq/yr
Sludge to Incineration*	0.018 G Bq/yr
Total Gas Production*	0.076 G Bq/yr

*Assumes that Gas (Methane) and sludge are incinerated @ WWTP, and that organic C conversion to CO_2 is 100%.

- Summary: Partitioning of Discharges to Hamilton Sewer System
  Total Discharge to Surface Water 0.35 + .074 = .42 G Bq/yr
  Total Discharge to Atmosphere 0.08 G Bq/yr

- Burlington Organic C Budget
  Influent 1.9 G Bq/yr
  Effluent Organic .095 G Bq/yr
  Effluent Inorganic C .84 G Bq/yr
  Total Effluent .93 G Bq/yr
  Gas .74 G Bq/yr
  Sludge to Landfill .23 G Bq/yr

- Summary: Partitioning of Discharges to Burlington Sewer System
  Discharge to Surface water 1.03 G Bq/yr
  Discharge to Atmosphere .74 G Bq/yr
  Sludge to Landfill .23 G Bq/yr

- Summary of WWTP Partitioning for Hamilton-Burlington
  - Discharge to surface water 1.5 G Bq/yr
  - Discharge to Atmposphere .82 G Bq/yr
  - Discharge to Landfill (underdrain) .23 G Bq/yr

- HH to WTP Intake
  - for HH, assume f=0 since 10% of WWTP discharge is inorganic C and the remainder is probably dissolved organics.
  - L. Ont.

$$C_{WTP} = \frac{(.01)(1.5 \text{ G Bq/yr} \times 10^9)}{3.2 \times 10^7}$$

$= 0.48\ Bq/m^3$

- Landfill
  - Average Solids Concentration when first placed.

$$\frac{.23\ G\ Bq/yr}{(10\ ha)(10^4 m^2/ha)(1.8\ m/yr)} = 1300\ \frac{Bq}{m^3}$$

  - Organic Decay and Release into Leachate.
    - Assume 1st year is worst case
    - Assume 95% of solids decay in one year from organics to CO_2 and that 50% of CO_2 volatilizes to air
    - Assume decay products do not adsorb to soil material
    - Leachate Mass Flow = 0.11 G Bq/yr
    - Return Flow to WWTP = 0.11 G Bq/yr

- WWTP (Hamilton) Incinerator
  - Feed Concentration = $(0.02 \times 10^9\ Bq/yr)/(1.2 \times 10^7\ kg/yr) = 2\ Bq/kg$
  - Concentration in Road Bed Material

$$= \left(2\ \frac{Bq}{kg} \times 1\ \frac{kg}{m^3}\right)(0.1) = 0.2\ Bq/m^3$$

- Hence overall partitioning
  - Neglect second cycle from WWTP to landfill
  - WWTP Intake 0.25 G Bq/yr
  - Discharge to Surface Water (0.6)(.11) + 1.5 = 1.6 G Bq/yr
  - Discharge to Atm (0.4)(.11) + (.82) = 0.86 G Bq/yr
  - $C_{WTP} = .51\ Bq/m^3$

(b) <u>Solid Waste Form</u>

- None

3. Co-57

(a) Liquid Waste Disposal

- No loss in sewer system.
- In body, Co-57 follows Ni characteristics. It is applied particularly with vitamin B 12, and excreted by the kidney, probably as ionic cobalt.
- Partitioning data for WWTP's is limited. Sludge concentrations are typically 8 ug/g, and of the same order as Ni.
- In lakes (Hesslein et al, 1980), experimental addition of Co-57 showed that a large fraction was particulate, similar to Fe-59, suggesting that it might act similarly in WWTP's.
- Assuming Co-67 acts similarly to Ni in WWTP, allocate WWTP disposal as
  - Effluent 1800 Bq/yr
  - Landfill 200 Bq/yr
- Surface Water Transport
  - $C/Co = 105/(105 + 22.5) = 0.82$
  - $C_{WTP} = (0.01)(0.8)(1800\ Bq/yr)/(3.2 \times 10^7 s/yr)$
    $= 4 \times 10^{-7}\ Bq/m^3$
  - C to City $= 2 \times 10^{-7}\ Bq/m^3$ assuming 50% removal due to flocculation/coagulation on WTP
- Incinerator concentration (WWTP) $= (200\ Bq/yr)/(1.2 \times 10^7\ kg/yr)$
  $= 10^{-4}\ Bq/kg$
- WWTP Disposal
  - Assume 1/10 dilution of Incinerator Waste in road bed materials
  - Concentration in Road Bed Material

$$= 10^{-4}\ \frac{Bq}{kg} \times \frac{1\ kg}{m^3}\ (0.1) = 10^{-5}\ Bq/m^3$$

(b) Solid Waste Disposal

- Assume 0.04 G Bq/yr is disposed as sorbed.
- This quantity is disposed to Burlington landfill with underdrain.
- Solid Waste concentration

$Co^1 = (4 \times 10^7 \text{ Bq/yr})/10^5 m^2/(1.8 m/yr) = 220 \text{ Bq/m}^3$

$Co = (220)(0.4)/1000/1.5 = 0.06 \text{ Bq/m}^3$

- i.e., Concentration in soil moisture in solid waste is 0.06 Bq/m^3

- Since underdrain is at bottom of landfill, transport is direct from soil moisture to underdrain.
- Mass flow to Underdrain

  $= (2.5 \times 10^4 \text{ m}^3/\text{yr})(.06 \text{ Bq/m}^3)$

  $= 1500 \text{ Bq/yr}$
- WWTP Partitioning of Underdrain Flow
  - To HH 150 Bq/yr
  - Back to Landfill 1500 Bq/yr
- Using surface water transport calculations;

  C to city $= 2 \times 10^{-9} \text{ Bq/m}^3$

(c) Overall Picture for Co-57

- C to city $= 4 \times 10^{-9} \text{ Bq/m}^3$
- Concentration in solid waste 220 Bq/m^3
- Concentration in incinerator solids (WWTP) $= 10^{-4}$ Bq/kg
- Discharge to Atm = 0

4. Cr-51

(a) Liquid Disposal

- no loss in sewer system
- WWTP data (Aulerbach et al, 1983) indicate Cr removal in plants ranging from 0% to 70% for "soluble" Cr and from 70% to 90% for total Cr. Mass Balance data for Cr-51 indicates that 77% goes to effluent and 23% to solid waste (Durham and Joshi, 1979).
- Hence WWTP disposal:
  - Sludge = (0.23)(3 G Bq/yr) = 0.7 G Bq/yr
  - WWTP Effluent = 2.3 G Bq/yr

- Surface Water Transport
  - $C/Co = 105/(105 + 15 + (9.36)(13.6)) = 0.42$
  - $C_{WTP} = (0.01)(0.4)(23 \times 10^8 \text{ Bq/yr})/86400/365 = 0.31 \text{ Bq/m}^3$
  - C to city = $(0.1)(0.31) = .03 \text{ Bq/m}^3$
- Incinerator (WWTP) Characteristics
  - Concentration in Feed = $(0.7 \times 10^9 \text{ Bq/yr})/(1.2 \times 10^7 \text{ kg/yr})$
    $= 60$ Bq/kg dried sludge
  - Concentration in Road Bed Material
    $= (60 \text{ Bq/kg} \times 1 \text{ m}^3/\text{kg})(0.1) = 6 \text{ Bq/m}^3$

(b) <u>Solid Waste Disposal</u>

- None

(c) <u>Summary Cr-51</u>

- C to city = 0.03 Bq/m^3
- Concentration in landfill = 0 Bq/m^3
- Concentration in Incinerator (WWTP) solids = 60 Bq/kg dried sludge
- Concentration in SWARU solids = 0
- Discharge to Atm = 0

5. <u>Ga-67</u>

(a) <u>Liquid Disposal</u>

- Loss in sewer system = $(1 - \exp(-.0089 \times 12 \text{ hr}))(77 \text{ G Bq/yr}) = 8$ G Bq/yr.
- No WWTP partitioning data found; assume that it is similar to Al (passive uptake) giving 20% removed to sludge.
- Hence WWTP disposal (Hamilton)
  - To sludge = $(0.2)(69) = 14$ G Bq/yr
  - To effluent = 51 G Bq/yr
  - Decay in plant = $(69 \text{ G Bq/yr}) \exp(-.213(.29)) = 4$ G Bq/yr

- Surface water transport (assume to be ionic)

  $C/Co = 105/(105 + 5 + (78)(13.3)) = 0.092$

  $C_{WTP} = (.01)(.092)(51 \times 10^9 \text{ Bq/yr})/3.15 \times 10^7 \text{s/yr} = 1.4 \text{ Bq/m}^3$

  C to city = 0.1 Bq/m^3, assuming 90% removal by Al flocculation

- WWTP Sludge Disposal
  - Incinerator Solids Conc. = $(14 \times 10^9 \text{ Bq/yr})(.118)/(1.2 \times 10^7 \text{ kg/yr})$
    = 138 Bq/kg dried sludge
  - Assume no Ga-67 volatilization in WWTP Incinerator
  - Average annual Ga-67 concentration in incincerator ash material
    = $(138 \text{ Bq/kg} \times 1 \text{ kg/m}^3)(0.1 \text{ m}^3/\text{m}^3)/(0.693/3.25 \times 365)$
    = 0.1 Bq/m^3 (including effects of decay)

(b) <u>Solid Waste Disposal</u>

- No source

(c) <u>Summary</u>

- C to City = .02 Bq/m^3
- Concentration in landfill = 0 Bq/m^3
- Concentration in STP Incinerator Solids = 1200 Bq/kg dried solids
- Concentration in SWARU Solids = 0
- Discharge to ATM = 0

6. <u>H-3 (Tritium)</u>

(a) <u>Liquid Disposal</u>

- Labelled Tritium on organics is fairly stable; assume no sewer system loss.
- Tritium is transported to WWTP in organic form.
- No WWTP partitioning data found. Assume decay processes in WWTP affect labelled tritium the same way they affect soluble organics.

- WWTP Partitioning of 2 G Bq/yr

  Effluent Organics = 0.1 G Bq/yr

  Respired Tritium in Activated Sludge (.44)(2) = .88 G Bq/yr

  Sludge (.12)(2) = .24 G Bq/yr

  Digester Gas (.39)(2) = .78 G Bq/yr
- WWTP Incinerator Solids Concentration = (.24 G Bq/yr)/(1.2 x 10^7 kg/yr)

  = 20 Bq/kg dry sludge
- Assume WWTP Incinerator volatilizes all tritium in sludge
- Hence Net WWTP Partitioning is
  - to HH : 0.1 G Bq/yr
  - To Atm: 1.9 G Bq/yr as H-3 gas = 1.6 G Bq/yr

    as CH_4 gas = .28 G Bq/yr

- Surface Water Transport
  - C/Co = 105/(105 + (.01)(13.6)) = .99 assuming no sorption of organics in HH, that decay rate of organics is .01 d^{-1}, and that tritium is lost by volatilization from HH.
- C_{WTP} = (0.01)(.99 x 10^8 Bq/yr)/(3.15 x 10^7) = .03 Bq/yr
- C to City = (0.4)(.03) = 0.01 Bq/yr assuming 60% removal of organics in WTP

(b) <u>Solid Waste</u>

- None

(c) <u>Summary</u>

- C to City = .01 Bq/yr
- Concentration in landfill = 0
- Concentration in WWTP Incinerator = 20 Bq/kg dry sludge
- Discharge to ATM = 1.9 G Bq/yr

7. I-125

(a) Liquid Disposal

- I-125 is a simple label on a fibrogen. It rapidly is converted to the body's iodine pool and excretion in urine.
- Using same partitioning as for I-131.
- Hence WWTP partioning
  - To sludge (.02%)(28 G Bq/yr) = 0.005 G Bq/yr
  - To effluent 28 G Bq/yr
- Surface water disposal
  - C/Co = 105/(105 + 0 + 13.6 x .693/60) = 1.0
  - C_{WTP} = (0.1)(1.0)(28 x 10^9)/3.2 x 10^7 = 9 Bq/m^3
  - C to City = 9 Bq/m^3
- WWTP Sludge Disposal
  - Incinerator Solids Conc: 0.6 Bq/kg dried sludge
  - Atmospheric input = 1 MBq/yr
- Road Bed Concentration

$$= 0.6 \frac{Bq}{kg} \times 1 \frac{kg}{m^3} \times 0.1 \frac{m^3}{m^3} \times \frac{1}{(0.693)(365)/8.05}$$

$$= 0.002 \ Bq/m^3$$

- Landfill Concentration = 0 Bq/m^3

(b) Solid Disposal

- None

(c) Summary

- C to City = 8 Bq/m^3
- Concentration in Landfill = 0 Bq/m^3
- Concentration in WWTP Incinerator = 0.6 Bq/kg dired sludge
- Atm input = 1 M Bq/yr

8. I-131

(a) Liquid Disposal

- Assume no loss in sewer system.
- For WWTP partitioning, there is a dichotomy. The sludge content (Durham and Joshi, 1979) indicates that 0.02 G Bq/yr are lost via sludge while no detectable quantity in the effluent suggests than less then this is lost in the effluent. But the loading to the plant is estimated at 80 G Bq/yr. Given the sludge loss, the loading would suggest that little removal will occur in the plant, giving an effluent concentration of 0.86 G Bq.L (20 PCi/L), a concentration which should be detectable. But maybe it isn't. Contact has not been reestablished yet with Joshi re his I-131 detection limit. He's in Asia.
- This partitioning (0.02% removal in sludge) fits with chemical ideas of removal. I-131 is estimated to enter the sewer system as an iodide. In this form, it is relatively biochemically inert, being not adsorbed and being taken up by bacteria into internal cellular fluids. Accordingly, a sludge removal of 0.02% is assumed.
- Assume no iodide conversion to I_2 by chlorination in WWTP effluent.
- Hence WWTP partitioning
  - To Sludge = 0.02 G Bq/yr
  - To Effluent = 80 G Bq/yr
- Surface water disposal (assumed as ionic; no adsorption)
  - $C/Co = 105/(105 + 0 + (.086)(13.6)) = 1.0$
  - $C_{WTP} = (.01)(1.0)(80 \times 10^9 \text{ Bq/yr})/3.15 \times 10^7 \text{s/yr} = 25 \text{ Bq/m}^3$
  - C to City = 25 Bq/m^3, assuming no removal in WTP
- WWTP Sludge Disposal
  - Incinerator Solids Conc. = $(2 \times 10^7 \text{ Bq/yr})/1.3 \times 10^7 \text{ kg/yr}$
    = 1.7 Bq/kg dried solids
  - Assume 20% of I-131 on sludge is volatilized giving
    Atmospheric input = 4 M Bq/yr
  - Waste Solids Concentration = $1.4 \text{ Bq/kg} \times \frac{1 \text{ kg}}{\text{m}^3} \times \frac{0.1 \text{ m}^3}{\text{m}^3}$
    = 0.1 Bq/m^3 in Road Bed

(b) Solid Waste Disposal

- No disposal

(c) Summary

- C to City = 24 Bq/m^3
- Concentration in landfill = 0 Bq/m^3
- Concentration in WWTP Incinerator = 1.7 Bq/kg dried solids
- Discharge to atmosphere = 4 M Bq/yr

9. Ni 63

(a) Liquid Disposal

- None

(b) Solid Waste Disposal

(1) Source 1

- .07 G Bq/yr sorbed to Lake Sediments disposed to Burlington landfill
- Conc. in landfill = $(7 \times 10^7$ Bq/yr$)/(1.8 \times 10^5 m^3/yr) = 390$ Bq/m^3
- Ni sorption - In pH range of 7, 100% of Ni sorbs to amorphorus manganese dioxide, 10% to goethite and 0% to silica (sand) for solution containing 0.02 M Ni and 25-50 m^2 of surface area per liter.
- Hence assume that in mixture of soils composing landfill, Ni-63 sorbs with low $K_D = 2$.
- In landfill, Co = $390/(1 + (2)(1.5)/0.1 = 12.6$ Bq/m^3 of moisture.
  - Leaching Rate = $(12.6\ Bq/m^3)(2.5 \times 10^4 m^3/yr)$
    $= 3.1 \times 10^5$ Bq/yr
- WWTP Partitioning of Underdrain
  - Ni is taken up by cells in a passive manner
  - Ontario WWTP records (1975-76) suggest 50% removal to sludge (Snodgrass, 1980)
  - Assume 20% to sludge

- Surface Water Partitioning
  - C/Co = 1.0 since f is assumed to be 0
  - $C_{WTP} = (0.1)(1.0)(1.5 \times 10^5)/3.15 \times 10^7 = 5 \times 10^{-5}$
  - Assuming 50% removal in WTP, C to City = 2×10^{-5} Bq/m^3

    This is insignificant

(2) Source 2

- Disposal of 1 electron capture detector to Hamilton landfill.
- Assume that it would be incinerated and that same percentage of activity as Am-241 is mobilized by incinerator
- Atm: 1% of 1 G Bq/yr = 0.01 G Bq/yr to atmosphere
- Landfill Calculations (Hamilton)
  - 10% of initial activity is lost in first year
  - assume activity is mobilized by rainfall
  - assume that 1% of landfill is influenced by corrosion of detector and hence that 1% of rainfall is influenced by detector.
  - Hence Critical Group exposure in landfill is to a concentration of $(0.1)(1\text{ G Bq/yr})/(0.01)(6 \times 10^5) = 1.6 \times 10^4$ Bq/m^3
  - Leachate concentration = $(0.1)(1\text{ G Bq/yr})/(0.1)/2.5 \times 10^3$

    $= 4$ M Bq/m^3
  - Leachate Flux = (0.1)(1 G Bq/yr) = 0.1 G Bq/yr
- Surface Water Partitioning
  - C/Co = 1.0
  - $C_{WTP} = (0.01)(1.0)(10^8\text{ Bq/yr})/3.15 \times 10^7 = 0.03$ Bq/m^3
  - C to city = .02 Bq/m^3

(b) Summary

- C to City .02 Bq/m^3 (due to electron capture detector)
- Landfill Concentration
  - 390 Bq/m^3 due to lake sediment source
  - 4×10^4 Bq/m^3 up to 1 G Bq/m^3 due to electron capture detector. The highest concentration is local; the remainder of landfill has 0 Bq/m^3

- Incinerator feed = 1 G Bq distributed in an electron capture detector
- Discharge to atmosphere 10 M Bq/yr

10. P-32

(a) Liquid Waste Disposal

- 3 G Bq/yr to sewer system, mainly from in vitro studies for DNA etc. for cancer research studies. It is a very low yield, suggesting that 1% ends up on organics with 99% remaining as phosphate ion.
- Assume all P-32 reaches WWTP as inorganic P.
- WWTP Partitioning Data
  - Hamilton obtains 90% P removal (to sludge) by sorption to iron oxides etc. in sewage.
  - Burlington obtains 80% P removal by biological uptake and alum precipitation.
- WWTP Partitioning Calculations
  - Assume all P-32 from in vitro studies goes to Hamilton STP.
  - Effluent = (0.1)(3) = 0.1 G Bq/yr
  - Sludge = (0.9)(3) = 2.7 G Bq/yr.
- WWTP Incinerator (Hamilton)
  - Sludge Concentration = $2.7 \times 10^9 / 1.2 \times 10^7$ kg/yr = 225 Bq/kg dried solid
  - Atm = 0
  - Disposal to Road Bed = 2.7 G Bq/yr
  - Road Bed Material Concentration
    = $(225 \text{ Bq/kg} \times 1 \text{ kg/m}^3)(.1 \text{ m}^3/\text{m}^3)(.693 \times 365/14.2)$
    = 1.3 Bq/kg on annual average due to in situ decay
  - Surface water partitioning
    - $C/Co = 105/(105 + (0.8)(25) + (.693 \times 13.6)/(14.2) = 0.84$
    - $C_{WTP} = (.01)(0.84)(0.3 \times 10^9)/3.15 \times 10^7 = 0.08 \text{ Bq/m}^3$
    - C to City = 0.02 Bq/m^3 assuming 75% removal in WTP

(b) Solid Waste

- no disposal

(c) Summary

- C to City = 0.01 Bq/m^3
- Landfill concentration 0 Bq/m^3
- Incinerator Feed 0 Bq/kg dried solids
- Flux to atmosphere = 0

11. P-33

(a) Liquid Waste

- Injected into natural water bodies; no waste
- Assume it is all injected into water bodies equivalent to Lake Ontario.
- C in Lake Ontario = 4×10^6 Bq/$1.6 \times 10^{12} m^3/10 = 2 \times 10^{-7}$ Bq/m^3
- Assume 75% removal in WTP
- C to city = 10^{-7} Bq/m^3. This is negligible.

(b) Solid Waste

- no source

(c) Summary

- C to City = 10^{-7} Bq/m^3
- No quantity of significance for Human exposure.

12. Po-210

(a) Liquid Waste

- no disposal considered

(b) Solid Waste

- Source: Po-210 is fused in glass microspheres for anti static devices for use in dust removal in photo development.
- 1700 devices, shipped in 1984 by 3M to all Canada in sizes of 5, 10, 25 and 40 mCi. Most are of the small size.
- Proportion the Canadian and Hamilton populations and assume that 10% are not returned to manufacturer for disposal to solid waste (3M statistics)

  = Hence, activity disposed to solid waste (1700 x 525,000)/25,000,000 x (0.1 x 10mCi)/(27 G Bq/mCi) = 1 G Bq/yr
- This number is contained in 36 devices/yr.
- Assume 75% of all devices go through incinerator (SWARU) serving 80% of population of Hamilton-Burlington.
- The portion of glass spheres which would crack in incinerator is unclear.

  Assume 10%, as in Am 241 case.
- Incinerator Characteristics
  - Mass flow to Incinerator (1 G Bq/yr)(0.75)(0.8) = 0.6 Bq/yr
  - Assume 1% to Atm = 10 M Bq/yr
- Landfill Characteristics (Hamilton)
  - Average landfill concentration, taking into account decay =

    $(0.8)(.99)(10^9 \text{ Bq/yr})/(6 \times 10^5 m^3/1.83 = 720 \text{ Bq/m}^3$
  - Average Landfill Concentration from incinerator residue

    $= 540 \text{ Bq/m}^3$
  - Average Leachate Concentration =

    $(0.1)(540)/(1 + (1000(1.5)/0.4) = .014 \text{ Bq/m}^3$
  - For a sorption coefficient of 1000, Po-210 will not migrate to Red Hill Creek in 20 years.
  - Assume 1% of Po-210 migrates to Red Hill Creek
  - Therefore flux from landfill = $(.014)(2.5 \times 10^3 m^3/yr)(0.01)$

    $= 0.4 \text{ Bq/yr}$
- Average Burlington Landfill Concentration

  $= (0.2)(10^9)/1.8 \times 10^5 m^3/1.83 = 600 \text{ Bq/m}^3$

- Surface Water
  - C/Co = 105/(105 + 5 + (1.83)(13.8)) = 0.78
  - C_{WTP} = (0.01)(0.78)(0.8)/3.2 x 10^7 = 10^{-10} Bq/m^3 which is insignificant.

(c) Summary

- C to city = 0
- Incinerator Feed
  - 0.4 B Gq per device
  - 60 Bq/kg dried sludge on average
- Landfill
  - 0.4 G Bq per device
  - Average Concentration = 720 Bq/m^3

13. S-35

(a) Liquid Waste

- 1.5 G Bq/yr purchased as methionine (amino acid containing sulfur in reduced (-2) oxidation state).
- Released from body in both urine and bial. In bial, S-35 is still in reduced state, but that in urine is in SO_4 state because only a little quantity of amino acid etc., are released through kidney. Assume S-35 is released predominately in bial.
- Assume remainder of S in amino acids which reach WWTP are converted to CO_2 + SO_4 in aeration tank except for 5% residual in effluent and 12% in sludge. This assumes that S in reduced state in organics partitions similar to carbon.
- WWTP Partitioning
  - Organics in effluent (.05)(1.5) = 0.075 G Bq/yr
  - Sludge (.12)(1.5) = 0.18 G Bq/yr
  - Inorganics in effluent = (.83)(1.8) = 1.2 G Bq/yr
  - Total in effluent = 1.32 G Bq/yr
- Surface water
  - C/Co = 105/(105 + (2.87)(13.6) + 0) = 0.73

- $C_{WTP} = (0.01)(1.32 \times 10^9)(0.73)/3.2 \times 10^7 s/yr$
  $= 0.29\ Bq/m^3$
- C to City = $0.3\ Bq/m^3$

- Incinerator (WWTP)
  - Concentration in WWTP Feed = $1.8 \times 10^8\ Bq/yr / 1.2 \times 10^7\ kg/yr$
    $= 15\ Bq/yr$
  - Assume 100% conversion to gas of reduced organic S
  - Input to Atm = $2 \times 10^8\ Bq/yr$

(b) Solid Waste

- = no disposal

(c) Summary

- C to City = $0.1\ Bq/m^3$
- Concentration in WWTP incinerator feed = 15 Bq/kg
- Concentration in Landfill = 0
- Input to Atm = 0.2 G Bq/yr

14. Se-75

None identified as produced and used.

15. Tc-99m

(a) Liquid Waste

- Column is milked twice weekly. Tc-99m is delivered daily from McMaster to Hospital.
- From medical literature, one gets the impression that not much is known about its body chemisty, relative to the other nuclides.
- It is added to the body as a chelate. Its preparation involves injection of the pertechnetate (presumably TcO_3^-) into a solution containing the chelate and Sn(II) which reduces the Tc to a IV oxidation state. Hence the

metal is injected as a chelate in a reduced III or IV oxidation state. Typical chelates are DPTA, EDTA, citrate, glutinate, DSMA.

- Its excretion is in the oxidation state that it passes through the bile or kidney.
- Presumably under an oxidized environment, it is rapidly reconverted to the pertechnetate form.
- Assume that Tc is partitioned in the WWTP similar to that of carbon and sulfur.
- Tc-99m is held up in body before release. It is estimated that 80% is excreted in 1 hour.

For Body, $(C_B)/C_{BO} = \exp(-k_B - \ )t$

Discharge to sewer system = $_{o}^{24} k_B C_{BO} \exp(-k_B - \ )t \ dt$

$= 0.66$ Co

Loading to Sewer system = (0.66)(878 Ci/yr) = 578 Ci/yr = 21T Bq/yr

- Decay in sewer system
  - Transport to WWTP = 21T Bq/yr exp (-0.693/6 hr x 12 hr) = 4 T Bq/yr
- Partitioning in WWTP
  - sludge 12%
  - Effluent 88%
  - Decay in plant due to hydraulic detention time of 12 hours results in effluent concentration of

    = (0.88)(4 T Bq/yr) exp (- (0.693 x 12)/(6)) = 0.67 T Bq/yr
  - Sludge retention time
    - o In A.S., assume 10d.
    - o In digestor, assume 10d.
  - Sludge flux to incinerator

    = (0.12)(4 T Bq.yr) exp (-(0.693 x 480)/(6)) = 0.4×10^{-12} Bq/yr

    Note: this is a very rough model for the sludge; refinements are needed.
  - Sludge concentration in incinerator

    = 0.4×10^{-12} Bq/yr/1.2×10^{7} kg/yr

    = 4×10^{-20} Bq/kg which is insignificant.

- Surface water partitioning
  - C/Co = 105/(105 + 0 + (1012)(13.6)) = 0.0075

- C_{WTP} = (0.01)(0.008)(0.67 x 10^{12}) exp (-0.693 (0.1 d)/(0.25 d)/3.2 x 10^7 s/yr
  = 1.2 Bq/m^3
- C to city = 0.16 exp ((-0.693)(6 hr)/6 hr) = 0.6
- C to People = 0.6 exp ((-0.693(12 hr)/6 hr) = 0.15 Bq/m^3

(b) Solid Waste

- No source

(c) Summary

- C to People in city 0.2 Bq/m^3
- Concentration in WWTP feed = 0
- Concentration in landfill = 0
- Discharge to Atmosphere = 0

16. Tl-201

(a) Liquid Waste Disposal

- chemically acts similar to K, but it is poisonous because it seeks out S groups
- given into the body as Tl^+; hence assume excretion as Tl^+
- WWTP Partitioning
  - Sludge (.001)(58 G Bq/yr) = 52 M Bq/yr (0.1% removal assumed)
  - Effluent 52 G Bq/yr
- Surface Water Partitioning
  - C/Co = 105/(105 + 0 + .693/74 x 24 x 365 x 13.6) = 0.086
  - C_{WTP} = (0.01)(0.086)(52 x 10^9)/3.2 x 10^7 s/yr
    = 2.0 Bq/m^3
  - C to city = 2 Bq/m^3 assuming no removal in WTP
- Incinerator (Hamilton WWTP)
  - Feed Concentration =
    52 x 10^6 Bq/yr exp ((-0.693 x 20 d)/3.08 d)/1.2 x 10^7 kg/yr
    = 0.05 Bq/kg

- Assume no input to atmosphere
- Disposal to Road bed material = 6.5×10^5 Bq/yr
- Road bed material concentration

  = (0.05 Bq/kg x 1 kg/m^3)(0.1 m^3/m^3)/82

  = 5×10^{-5} Bq/m^3 on an annual average basis.

(b) Solid Waste Disposal

- None

(c) Summary

- C to City = 2 Bq/m^3
- Conc. in Incinerator feed = 0.05 Bq/kg
- Landfill Concentration = 0 Bq/m^3
- Atmospheric Input = 0

17. Zn-65

(a) Liquid Waste Disposal

- none

(b) Solid Waste Disposal

- Adsorbed to sediments disposed to landfill (Burlington)
- Landfill Characteristics (Burlington)
  - Concentration = 20×10^6 Bq/yr/$1.7 \times 10^5 m^3$/yr = 100 Bq/m^3
  - porewater concentration = 100/(1 + (10)(1.5)/(0.1)) = 0.8 Bq/m^3
  - Leachate Mass flow = (0.8 Bq/m^3)($2.5 \times 10^3 m^3$/yr) = 2000 Bq/yr
- WWTP
  - Assume 80% to effluent. Hence 1600 Bq/yr

    20% to sludge. Hence 400 Bq.yr which goes back to landfill
- Surface Water Partitioning
  - C/Co = 105/(105 + (0.2)(25) + (24.7)(13.6)) = 0.24

- $C_{WTP} = (0.01)(0.24)(1600)/3.2 \times 10^7 s/yr = 1 \times 10^{-7}$ Bq/m^3
  which is negligible

(c) Summary

- C to City 0
- Concentration to Incinerator = 0
- Landfill Concentration 100 Bq/m^3
- Atmosphere Input 0

D.2 Assumptions Describing Disposal of Rad Waste Cleanup from Hospitals, etc.

- Assume waste goes only to Hamilton Solid Waste System
- Assume 12 hr residence time in garbage bins before pick-up and delivery to SWARU or landfill.
- Assume Hamilton garbage has following characteristics.
  - Mass disposed to landfill/yr =
    394,000 x 1.24 increase x 0.82 T/(person-yr) x .908 kg/(T) = 3.6×10^8 kg/yr
  - Mass to SWARU (=75%) = 2.7×10^8 kg/yr
  - Volume of solid waste collected (100 kg/m^3 bulk density)
    = 3.6×10^6 m^3/yr
  - Volume of solid waste to SWARU = 2.7×10^6 m^3/yr
  - Volume of solid waste from SWARU = 2.7×10^5 m^3/yr
  - Volume of landfill = 6×10^5 m^3/yr
- Calculation Formula
  - Decay in Collection System = exp (0.693/(t 1/2 in day) x 0.5 d)
  - Mass to be disposed = (Mass Input - Decay in Collection)
  - Mass to Landfill = (Mass to be Disposed - Loss in SWARU)
  - Decay Factor in Landfill = 0.693/(t 1/2 in day) x 365 d
  - Concentration landfill = Mass/Volume/Decay Factor
- Mass loss to Solid Waste
  - Assume 10mCi vials in 10 ml quantities
  - Assume spillage of 1 drop (0.1 ml) for each usage = 1% loss to solid waste
  - Assume 10% of kleenex, towels, gloves etc., are not recycled to Chalk River.

- Calculations
  - Calculations of concentration of various points in the solid waste system are given in the attached table, using the above assumptions.

Appendix D.2 Solid Waste Assumptions and Sample Landfill Calculations

Literature

- National Average = 2.82 lb/capita/day (± 2.08: standard deviation)
  Source Municipal Waste Statistics for Canadian Communities of over 100,000 (1976-1977) EPS, E.C., EPS 3-EC-79-9. Oct 1979

- Burlington = 2.2 lb capita/day from residential sources (Walker, Wright, Proctor & Young: Stage 1 Waste Needs and Systems Analysis: Report for Municipality of Halton, May 1983)

- Assumption made 3 lb/capita/day of solid waste

Allocation of Solid Waste Disposal

Apartments

- # of apartment units with incinerators 35 buildings with 9322 apartment units give 124 units/bldg
- assuming same number across Hamilton-Burlington in buildings known to have apartment incinerators gives 6422 apartment units
- assuming 3 people per unit gives 19,300 people with apartment incinerators
- Burlington population 117,000. Solid waste to landfill
- Hamilton population 408,000. Solid waste to incinerator (SWARU)
  Due to breakdowns, it is assumed that 1/4 of time Hamilton's solid waste goes to landfill.

These assumptions give the following populations:

- Waste disposal to incinerator then to landfill without underdrain 296,000
- Waste disposal direct to landfill without underdrain 98,000

- Waste disposal to landfill with underdrain 112,000
- Waste disposal to apartment incinerator to landfill without underdrain 19,000

Geometry of Landfill

- Assumptions
  - density 0.5 ton/yd^3 of raw
  - Burlington production rate 0.82 ton solid/capita/yr
  - Planning life of facility 20 yr
  - Burlington - No incineration
  - Hamilton - Incineration reduces volume by 90%
  - Contingencies result in following landfill requirements
    - Burlington = 0.5 ton/yd^3
    - Hamilton = 0.5 ton/yd^3 (from Walker, Wright & Young)
  - No significant change in population
  - Depth of landfill = 10 yd^3

- Landfill Area Requirements
  - Burlington approx. 100 acres (40 ha)
  - Hamilton approx. 330 acres (130 ha)

- Yearly depth of garbage placed
  - Hamilton - 6 m
  - Burlington - 1.8 m

Hydrology of Landfill

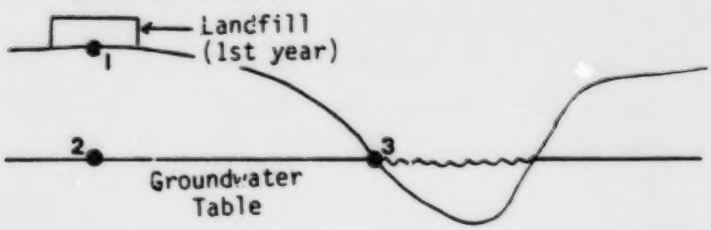
- Assume net infiltration into landfill during landfill spreading is 10 in/yr.
- Assume that landfill is filled in 10 ha sections (i.e., that source material to groundwater in first year is from a 10 ha section).
- Assume that natural water table is 3 m below land upon which first solid lift is placed.
- Assume critical period for transport to groundwater is release of radionuclide during first few years of operation, based on the reasoning that release from higher levels will have a longer distance to travel to reach groundwater and will be sorbed in upper layers.

- Assume that Hamilton's landfill is 150m from Red Hill Creek, whil Burlington's landfill is underlain by a sewer collection system which recycles leachate to the Waste Water Treatment Plant.
- Assume that leachate reaches surface streams or leachate collection system without significant groundwater dilution.

Model for Landfill Transport

1. Hamilton

Definitional Sketch



Assumptions

- For Zone 1-2 and Zone 2-3, assume diffusion is negligible
- Assume adsorption coefficient for 1-2 and 2-3 is the same

Model for 1-2

$$0 = v \frac{dC}{dx} - \left(1 + \frac{K_D \rho s}{\varepsilon} \right) C$$

Solution 1-2

$$\frac{C}{Co} = \exp \left[- \lambda \left(1 + \frac{K_D}{\varepsilon} \rho s \right) \frac{x}{v} \right]$$

Idealization for Modelling Unsaturated Zone

- soil is sandy, porosity 0.4, soil density 2.5 g/cc
- moisture occupies 25% of void spaces
- 40 rainfall events/yr, resulting in 10 day period between rainfall events

- Average rainfall uses 6 hr to pass through unsaturated zone to groundwater table
- Average rainfall results in 0.25 in of infiltrating water
- $Co' = (CR)\ (10)\ \frac{Bq}{m^2 d} \times d/(0.25\ in \times \frac{2.45\ cm}{in} \times \frac{.01m}{cm}) = 1575\ CR\ \frac{Bq}{m^3}$

- $Co = Co'/(1+K_D \rho S/\theta)$

<u>Sample Calculations for Am-241 for Position 1-2</u>

- Hamilton $CR = \frac{0.038\ GBq/yr}{365\ d/yr \times 10\ ha \times 10^4\ m^2/ha}$

  $= 1.0\ Bq/m^2/d$

  $Co' = 1575\ Bq/m^3$ of water

  $Co = 1575\ Bq/m^3/(1+(3000)\ (1.5)/0.4) = 0.14\ Bq/m^3$

- Assuming steady state

  $= 0.692/458\ yr \times 365d = 4.2 \times 10^{-6} d^{-1}$

  $\frac{C}{Co} = \exp\ (-4.2 \times 10^{-6}((1+(3000)\ (1.5)/0.4)0.25\ d) = 0.99$

  $C = 0.14\ Bq/m^3$

- Effects of transient movements. Assuming that water moved 3 m vertically downward in 6 hr gives v = 12 m/d.

  $\frac{v}{V_c} = (1+\frac{K_D}{\varepsilon} s) = (1+(3000)\ (1.5)/0.4) = 10^4$

  $V_c = 10^{-3}\ m/d$

In 1 yr, medium point of Am241 front would have moved $(10^{-3})(365) = 0.4$ m
To move 2 m vertically downward requires 8 yr.

- Conclusion concerning transient effects: for addition of an annual lift of solid waste and using a source strength of 0.038 GBq/yr for 1 year, and a markedly lower source strength in subsequent years, steady state conditions will result in a

substantial overestimate of the concentration entering groundwaters. But steady state will be used for initial calculation purposes.

- Burlington

CR = .000013GBq/yr/(365 x 10 x 100) = 3.6×10^{-13} GBq/m^2/d =
= 3.6×10^{-4} Bq/m^2/d

Co' = 0.6 Bq/m^3 of infiltrating rain water

Co = 0.6/(1+(3000)(1.5)/0.4) = 5×10^{-5} Bq/m^3

C = 5×10^{-5} Bq/m^3

Sample Calculations for Am-241 for Position 2-3

- Hamilton
  - Assume time of travel from landfill to Red Hill Creek for conservative substance is 1 yr

Steady State

$\frac{C}{Co}$ = exp (-4.2×10^{-6} (1+(3000)(1.5)/0.4) 365) = 3.2×10^{-8}

Hence C = 4.5×10^{-9} Bq/m^3

Travel Time

Vc = (150 m/yr) (10^{-4}) = .015 m/y

In 20 yr, medium point of Am-241 front would have moved 0.3 m

Hence over operating life of landfill, front will not have reached Red Hill Creek.

To be extremely conservative, assume that .01% of the groundwater concentration reaches Red Hill Creek

Hence C = 10^{-5} Bq/m^3

Flux = QC

$$= (10\ \text{ha})\ \frac{(10\ \text{in})}{\text{yr}}\ \frac{.0254\text{m}}{\text{in}}\ \frac{(\times 10^4\text{m})}{\text{ha}}\ (C)$$

= 0.3 Bq/yr to Red Hill Creek

- Burlington
  - Assume that leachate collection system obtains all leachate and that it is transported to wastewater treatment plant
  - Mass flow to waste water treatment plant

    $= (10\ \text{ha})\ \frac{(10^4 m^2)}{\text{ha}}\ \frac{(10\ \text{in})}{\text{yr}}\ \frac{(0.254 m)}{\text{in}}\ (5 \times 10^{-5} Bq/m^3)$

    $= 1\ Bq/yr$ to WWTP

Summary Disposal Assumptions for Garbage

- Hamilton - 394,000 people x 1.24 increase x 20 yr/person-yr x 2 yd^3/ton

  $= 16 \times 16^6 yd^3$

  = 330 A

- Burlington - 112,000 people x 1.24 increase x 20 yr x 0.82 x 2yd/ton

  $= 4.6 \times 10^6\ yd^3$

  = 94 A

- 75% of Hamilton garbage goes to SWARU; 1/4 goes direct to landfill.

APPENDIX E

Metabolism and Mode of Excretion of Selected Radionuclides Employed in Research and Medicine

METABOLISM AND MODE OF EXCRETION OF SELECTED RADIONUCLIDES EMPLOYED IN RESEARCH AND MEDICINE

It will be assumed that, in the absence of isotope-specific information, and chemically and biochemically speaking, radionuclides behave similarly to the stable isotope or most common radioisotope of the parent element.

Americium (^{241}Am)

^{241}Am is sometimes used as a gamma source in the clinical setting (e.g., spectrometer calibration source and external excitation source for in situ determination of stable iodine by x-ray fluorescence spectrometry), and is also present in smoke detectors for this purpose. Am^{3+} is the most common oxidation state (1). In urine, $^{241}Am^{3+}$ is present as the complex of naturally occurring citrate (2). By analogy with plutonium, which is also excreted as the citrate complete in urine (3), $^{241}Am^{3+}$ is likely bound to the serum iron-transport protein, transferrin (4). It is probably secreted only to a small extent in the bile (perhaps as a bicarvonate complex) (5). The tendency of Am^{3+} to hydrolyze appears comparable to the lanthanide and aluminum trivalent ions.

Carbon (^{14}C)

^{14}C-Compounds are used routinely in biological and biochemical research. The major medical use of ^{14}C is in gastrointestinal uptake studies (6). The clinically most useful tests involve absorption of labelled bile acid, fat, lactose and xylose (7). In most cases, $^{14}CO_2$ is measured in the breath, which constitutes a significant excretion pathway. Fecal and urine excretion also occurs in these tests. For example, in the bile acid test, 20% of dose occurs in the stools, with the bulk being expired in the breath. By comparison in the lactose test, 20% occurs in breath, 40% in urine and the remainder in the feces (7). Presumably, the incompletely metabolized ^{14}C excreted in the urine and feces would, on biodegradation, end up as ambient $^{14}CO_2$, which would subsequently enter the food chain through the photosynthetic pathway.

Cobalt (^{57}Co, ^{58}Co and ^{60}Co

Cobalt is mainly excreted in the urine (8). Its known biochemistry revolves around Vitamin B_{12}, which must be supplied in the diet in its physiologic active form (8). ^{60}Co, ^{58}Co and ^{57}Co are used mainly in nuclear medicine to study Vitamin B_{12} malabsorption, and are administered as Vitamin B_{12} (6, 7, 9, 10). When the tissue binding sites are saturated as in the Schilling test, about 30% of the absorbed Vitamin B_{12} is excreted in the urine unchanged by glomerular filtration and without reabsorption (7). Protein-bound Vitamin B_{12} is stored in the liver from which it is slowly released to the blood (7, 9).

Chromium (^{51}Cr)

Chromium-51 is employed mainly in the assessment of red blood cell survival, blood loss and protein loss (6, 7, 9, 10). The first two applications involve labelling erythrocytes with ^{51}Cr-chromate, which, after uptake, is reduced intracellularly to Cr^{3+} and labels haemoglobin. $^{51}Cr^{3+}$-labelled human serum albumin is injected in determining intestinal loss of protein. Normally, less than 1% of the radioactivity of injected ^{51}Cr-labelled albumin is excreted in the feces, and ^{51}Cr from labelled erythrocytes is similarly lost entirely by renal clearance (7). In the diseased state, fecal protein losses may correspond to 2 to 40% of the injected ^{51}Cr dose, while significant losses (e.g., equivalent to 50 mL of blood daily, compared to 1 mL normally) also occur in pathologic occult bleeding (7). The biological half-life of the erythrocyte-associated ^{51}Cr is 50 to 60 days, compared to 25 to 30 days for red blood cell survival (11). In the urine, chromium is present as Cr^{3+} (12), perhaps bound to citrate by analogy to Am^{3+}. The Cr^{3+} ion's tendency to hydrolyze resembles Al^{3+} and Fe^{3+} (13).

Gallium (^{67}Ga)

$^{67}Ga^{3+}$ as the citrate complex is employed in diagnostic scanning of inflammatory and malignant lesions (6). About 40% is excreted in the first five days (15 to 20% renal and 20 to 25% in feces - the exact weighting depends on dose). The renal route is the most prominent in the first 24 hours (e.g., 12% of injected dose) with the fecal route dominating later (9, 14). The solution chemistry Ga^{3+} resembles Al^{3+} and Fe^{3+} (including their propensity to form hydroxo complexes) (13, 15).

Iodine (^{123}I, ^{125}I, ^{131}I)

^{131}I is used in thyroid iodide uptake tests, in kidney function studies, in thyroid scanning, and in the treatment of hyperthyroidism and thyroid cancer (6, 7, 9, 10). ^{123}I has been suggested for thyroid uptake measurements (7, 10), and ^{125}I is employed in renal clearance measurements and in leg scanning (7). For thyroid work, the iodine isotope is administered as the iodide ion, in glomerular filtration rate studies as ^{125}I-iothalamate, in effective renal plasma flow as ^{131}I-hippuran, and as ^{125}I-labelled fibrinogen in leg scanning. Iodine (from all sources) is excreted mainly in the urine as iodide, with smaller amounts appearing in the feces and sweat (8, 9). Three iodine pools have been identified: plasma inorganic iodide, the intrathyroidal iodine, and that covalently bound to the thyroid hormones. The iodine from the latter is liberated in the tissues and is returned to the iodide pool (8).

Radioisotopes of iodine are also used extensively in research (in biochemistry, immunology, etc.).

Indium (^{111}In)

The labelled chelate, ^{111}In-DTPA (DTPA is diethyltriaminepentaacetic acid) is favoured for cerebrospinal fluid flow studies (6, 10). It is rapidly excreted by the kidneys by glomerular filtration (6, 9). ^{111}In is also used to label leukocytes and platelets for imaging, kinetic and survival studies (7). A lipid-soluble complex of 8-hydroxyquinoline is the vehicle for cellular uptake of $^{111}In^{3+}$. Since radioactivity accumulates in both the liver and kidneys, excretion is likely by both routes (7). The free ion, In^{3+}, binds strongly to the serum iron-protein transferrin like Cr^{3+} and Ga^{3+}. The chemistry of In^{3+} is similar to Ga^{3+} (see page ii).

Nickel (^{63}Ni)

The use of $^{63}Ni^{2+}$ seems to be limited to laboratory tracer work. Although the exact amount of nickel excreted in bile has not been established, urinary excretion as Ni^{2+} (likely complexed to the amino acid L-histidine) is an important pathway (8, 16). Exposure to water-soluble nickel salts in the workplace has shown that the absorbed Ni^{2+} is excreted in the urine with a half-life of one to two days (17). Ni^{2+} does not hydrolyze below pH 7 (13).

Phosphorus (^{32}P)

^{32}P is employed in biochemical research, although its current therapeutic use in the treatment of polycythemia and leukemia has waned (10). When ^{32}P-phosphate is given orally or intravenously, it accumulates in bone. Between 25 to 50% of the dose is excreted by the kidney in the first four to six days, which is followed by a rate of excretion of $<$ 1% of the dose per day. In oral administration, about 25% remains unabsorbed and appears in the feces (18).

Sulphur (^{35}S)

^{35}S-tagged amino acids are employed in life sciences research. The major metabolite of sulphur-containing amino acids is the sulphate ion which is excreted primarily in the urine (19).

Selenium (^{75}Se)

^{75}Se-selenomethionine is employed in the imaging of the parathyroid glands and the pancreas (10). About 80% of the administered ^{75}Se is eliminated in the urine and approximately 15% in the feces. The remainder is accounted for in the expired breath, sweat, hair, nails and skin. Half-lives for the various excretion phases range from $<$1 day to 220 days (9). The normal urinary metabolite is $(CH_3)_3Se^+$, and $(CH_3)_2Se$ occurs in exhaled breath (8, 20).

Technicium (^{99m}Tc)

^{99m}Tc currently is the single most important radion lide. It is a γ emitter free of emission and with a $t_{1/2} \cong 6$ hours. It is employed for the imaging of most of the major body organs (6, 7, 9, 10). $^{99m}TcO_4^-$, pertechnetate, is used in diagnostic scanning of the brain and the thyroid gland. The pertechnetate ion is strongly reabsorbed by renal tubules. About 30% of the injected dose appear in the urine during the first day, with about 40% of the dose occurring in the feces by day 4 (9). ^{99m}Tc-chelates are available for the imaging of specific organs (e.g., lung, liver and bone) (10, 21). Examples of chelating agents employed are: diethylenetriaminepentaacetic acid (DPTA) and EDTA for kidney imaging; pyrophosphate and methylenediphosphonate for bone imaging; and

penicillamine, tetracycline and iminodiacetic acid derivatives for the liver. In these chelates, the Tc is likely in the IV oxidation state, although some Tc(III) and Tc(V) have also been reported (22, 23). Kidney imaging agents appear to be largely excreted unchanged, as are hepatobiliary agents (by the liver in this case). Lack of metabolism also appears to characterize the bone imaging complexes which are excreted primarily in the urine (9, 21). After biodegradation of the ligand, the Tc will most likely be reoxidized to TcO_4^- (22).

Thallium (^{201}Tl)

Thallium-201 (administered as TlCl) is employed in myocardial visualization (6, 10). The physiological basis for this application is that Tl^+ resembles K^+ and is handled similarly by the body. The amount of Tl^+ excreted in the urine is about three times that excreted fecally (24, 25, 26). In man, excretion continues for three months in urine and 35 days in feces when administered parenterally (i.e., injected), as is the clinical practice.

Tritium (^3H)

Tritiated compounds are useful in biochemical and related research. ^3H_2O has been used in isotope dilution methods for the determination of total body water (9). It has a biological half-life of 11.5 days (9). ^3H-exchanges with all exchangeable and labile hydrogens (on water, proteins, carbohydrates). Because water is most ubiquitous, urine must be the major excretion pathway.

Zinc (^{65}Zn)

$^{65}Zn^{2+}$ is used in biological, biochemical and related research. Zinc leaves the body largely by way of the feces, and the amount of zinc excreted in the urine is small (0.3 to 0.6 mg/day) (8). Zn^{2+} does not hydrolyze significantly below pH 8 (13).

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APPENDIX F

Glossary of Symbols and Terms

GLOSSARY OF SYMBOLS AND TERMS

Symbols Used in Model Formulae

Symbol	Formulae First Used In	Definition
H	8.1	effective dose to receptor
Da	8.1	absorbed dose in air
w	8.1	conversion from absorbed to effective dose
Ø	8.1	gamma photon flux density
E	8.1	total emitted gamma energy per disintegration
a	8.1	mass absorption coefficient of gamma photons in air
	8.3	the sum of
E_i	8.3	gamma energy of transition i
f_i	8.3	fractional abundance of transition i
C	8.4	source concentration
	8.4	density of source material
mi	8.4	mass attenuation coefficient for gamma photon of energy E_i
i	8.4	linear attenuation coefficient for gamma photon of energy E_i
B	8.4	build-up factor
R	8.6	dimensions
h	8.6	dimensions
b	8.6	dimensions
k	8.6	h/R
b	8.6	b/R
d	8.8	thickness of sludge deposit
W	8.8	loading rate
DCF	8.9	dose conversion factor (see Appendix C)
C	8.11	radioisotope concentration
I	8.11	intake rate
T	8.11	exposure time

M	8.12	dust loading in air
V	8.14	volume of building
n	8.14	number of air charges per hour
f		fraction of radioisotope which is particulate in surface water
pi	9.1	proportion of population in zone i
S	9.2	shielding factor
v_g	9.3	deposition velocity
g	9.3	radioisotope decay rate
OF	9.5	occupancy factor (fraction of time exposed)
LFR	10.4	landfill filling rate
ARV	10.4	annual rainfall volume
K_D	10.4	linear distribution coefficient
P_{ij}	9 and 10	transfer parameter from compartment i to compartment j
Q	10.15 (10.12)	average annual flow rate
q	10.12	hydraulic loading
A	10.12	surface area
g	10.12	settling rate of particles
	10.12	effect of lake/bay exchange on washout
$\bar{t}$	10.15	detention time
R	10.21	removal in sewage treatment plant
k_w''	10.22	fraction of drinking water affected by radioisotopes
LO		Lake Ontario
WTP		Water Treatment Plant
HH		Hamilton Harbour

Terms

Critical Group:	Those individuals who potentially receive the largest radioisotope doses. These are calculated both for workers handling wastes and for members of the general population.
Collective Dose:	The probable radioisotope dose to members of the general population.
Leachates:	Liquid effluents from a municipal landfill site.
In vivo:	Inside the living organism.

In vitro:	Outside of living organisms (e.g., in test tube).
Redox Potential:	The properties of the environment in which a chemical is found to oxidize or reduce that chemical.
STP:	Sewage Treatment Plant
WWTP:	Wastewater Treatment Plant
Transfer Model:	Mathematical model or algorithm describing how radioisotopes move through the environment.
Partition:	Breakdown of the percentage of the radioisotope going into the environment which enters each particular environmental component (e.g., atmosphere, water, soil).
Pathway:	The route that a radioisotope takes in passing through the environment.
Open Source:	Materials whose disposal is not regulated.
Closed Source:	Materials which legally must be sent to an AECL disposal location.

APPENDIX G

Derivation of Source Terms

TABLE 6.1:

HAMILTON WWTP PARTITION FACTORS

RADIO-ISOTOPE	LOADING TO SEWER Bq/a	LOSS IN SEWER	WWTP LIQUID STREAM: FRACTION TO AIR	WWTP LIQUID STREAM: FRAC TO SLUDGE	WWTP LIQUID STREAM: LOSS TO DECAY	WWTP LIQUID STREAM: FRAC TO EFFLUENT	WWTP SLUDGE STREAM: SLUDGE: LOSS TO DECAY	WWTP SLUDGE STREAM: SLUDGE: FRAC TO EFFLUENT	WWTP SLUDGE STREAM: DIGESTER: FRACTION TO AIR	WWTP SLUDGE STREAM: DIGESTER: LOSS TO DECAY	WWTP SLUDGE STREAM: DIGESTER: FRAC TO EFFLUENT	WWTP SLUDGE STREAM: INCINERATOR: FRACTION TO AIR	WWTP SLUDGE STREAM: INCINERATOR: FRAC TO ASH
H3	2.00E+09		4.40E-01	5.10E-01		5.00E-02		1.00E+00	7.65E-01		2.35E-01	1.00E+00	
C14	5.00E+08			1.60E-01		8.40E-01		1.00E+00	7.60E-01		2.40E-01	1.00E+00	
P32	3.00E+09			9.00E-01		1.00E-01		1.00E+00			1.00E+00	1.00E-02	2.50E-01
P33	0.00E+00												
S35	1.50E+09			1.20E-01		8.80E-01		1.00E+00			1.00E+00	1.00E-02	8.90E-01
Cr51	3.00E+09			2.30E-01		7.70E-01		1.00E+00			1.00E+00	1.00E-02	9.90E-01
Co57	2.00E+03			1.00E-01		9.00E-01		1.00E+00		3.00E-02	9.70E-01	1.00E-02	9.90E-01
Ni63	0.00E+00												
Zn65	0.00E+00												
Ga67	7.70E+10	1.04E-01		2.00E-01	5.20E-02	7.48E-01		1.00E+00		8.82E-01	1.18E-01	1.00E-02	5.00E-01
Se75	0.00E+00												
Tc99m	2.10E+13	8.10E-01		1.20E-01	7.33E-01	1.47E-01	1.00E+00	9.10E-13		1.00E+00	9.10E-13	1.00E-02	5.00E-02
I125	2.80E+10			2.50E-04		1.00E+00		1.00E+00			1.00E+00	1.00E-02	9.90E-01
I131	8.00E+10			2.50E-04		1.00E+00		1.00E+00			1.00E+00	1.00E-02	7.50E-01
Tl201	5.80E+10	1.06E-01		1.00E-03	5.50E-02	9.44E-01	8.95E-01	1.05E-01		8.95E-01	1.05E-01	1.00E-02	5.00E-01
Po210	0												
Am241	0												

TABLE 6.2:
HAMILTON WWTP CALCULATIONS

RADIO-ISOTOPE	LOADING WWTP Bq/a	MASS FLOW EFFLUENT Bq/a	MASS FLOW EFFLUENT Bq/s	MASS FLOW TO SLUDGE Bq/a	MASS FLOW TO DIGESTER Bq/a	MASS FLOW DIGESTER EFFLUENT Bq/a	MASS FLOW TO WWTP INC. ASH Bq/a	LOSS TO AIR VIA AERATOR Bq/s	LOSS TO AIR VIA DIGESTER Bq/s	LOSS TO AIR VIA STACK Bq/s	CONC. AERATOR Is Bq/cc	CONC. TO SLUDGE FILTERS Bq/cc	CONC. IN DRY ASH Bq/cc	STACK RELEASE Bq/s
H3	2.00E+09	1.00E+08	3.16E+00	1.02E+09	1.02E+09	2.40E+08	0.00E+00	2.78E+01	2.47E+01	7.59E+00	1.00E-05	3.33E-03	0.00E+00	3.23E+01
C14	5.00E+08	4.20E+08	1.33E+01	8.00E+07	8.00E+07	1.92E+07	0.00E+00	0.00E+00	1.92E+00	6.08E-01	4.46E-06	2.67E-04	0.00E+00	2.53E+00
P32	3.00E+09	3.00E+08	9.49E+00	2.70E+09	2.70E+09	2.70E+09	6.75E+08	0.00E+00	0.00E+00	8.54E-01	2.68E-05	3.75E-02	5.63E-02	8.54E-01
P33	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
S35	1.50E+09	1.32E+09	4.18E+01	1.80E+08	1.80E+08	1.80E+08	1.60E+08	0.00E+00	0.00E+00	5.70E-02	1.34E-05	2.50E-03	1.34E-02	5.70E-02
Cr51	3.00E+09	2.31E+09	7.31E+01	6.90E+08	6.90E+08	6.90E+08	6.83E+08	0.00E+00	0.00E+00	2.18E-01	2.68E-05	9.58E-03	5.69E-02	2.18E-01
Co57	2.00E+03	1.80E+03	5.70E-05	2.00E+02	2.00E+02	1.94E+02	1.92E+02	0.00E+00	0.00E+00	6.14E-08	1.79E-11	2.69E-09	1.60E-08	6.14E-08
Ni63	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zn65	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ga67	6.90E+10	5.16E+10	1.63E+03	1.38E+10	1.38E+10	1.63E+09	8.14E+08	0.00E+00	0.00E+00	5.15E-01	5.84E-04	2.26E-02	6.78E-02	5.15E-01
Se75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tc99m	3.99E+12	5.87E+11	1.86E+04	4.79E+11	4.36E-01	3.96E-13	1.98E-14	0.00E+00	0.00E+00	1.25E-22	5.24E-03	5.51E-24	1.65E-24	1.25E-22
I125	2.80E+10	2.80E+10	8.86E+02	7.00E+06	7.00E+06	7.00E+06	6.93E+06	0.00E+00	0.00E+00	2.22E-03	2.50E-04	9.72E-05	5.78E-04	2.22E-03
I131	8.00E+10	8.00E+10	2.53E+03	2.00E+07	2.00E+07	2.00E+07	1.50E+07	0.00E+00	0.00E+00	6.33E-03	7.14E-04	2.78E-04	1.25E-03	6.33E-03
Tl201	5.19E+10	4.89E+10	1.55E+03	5.19E+07	5.44E+06	5.72E+05	2.86E+05	0.00E+00	0.00E+00	1.81E-04	4.37E-04	7.94E-06	2.38E-05	1.81E-04
Po210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Am241	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

NOTE: COMPUTER - B:TABLE2

	1	2	3	4	5	6
1	TABLE G.5					
2	SURFACE WATER FACTORS					
3				WWTP INCIN		
4	RADIO-	HALF	R-ISOTOPE	DECAY	(C/Co)	(C/Co)
5	ISOTOPE	LIFE	DECAY RATE	FACTOR	M.H.	L.O.
E						
7	H3	12.3 yr	.056/yr	1	0.99	0.7
8	C14	5700 yr	.00042/yr	1	1	0.7
9	P32	14.2 d	.0488/d	0.85	0.84	0.7
10	P33	24.4 d	.028/d			
11	S35	88 d	.0078/d	1	0.73	0.7
12	Cr51	27 d	.0257/d	0.9	0.42	0.7
13	Co57	220 d	.00315/d	1	0.82	0.7
14	Ni63	125 yr	.0055/yr	1	1	0.7
15	Zn65	24.7 d	.0281/d	0.91	0.24	0.7
16	Ga67	3.25 d	.213/d	0.52	0.092	0.68
17	Se75	120 d	2.1/yr	1		0.7
18	Tc99m	.25 d	2.77/d	0.051	0.0075	0.53
19	I125	60.2 d	.0115/d	1	1	0.7
20	I131	8.05 d	.0861/d	0.76	1	0.7
21	Tl201	3.08 d	.225/d	0.5	0.086	0.68
22	Po210	138 d	1.83/yr	1	0.78	0.7
23	Am241	458 yr	.0015/yr	1	0.97	0.7
24						
25						
26	NOTE: COMPUTER - B:TABLE5					

TABLE 6.6

FACTORS FOR RADIOISOTOPES IN SOLID WASTE

RADIO-ISOTOPE	LOADING TO SOLID WASTE (Bq/a)	DECAY FACTOR IN COLLECTION	DIRECTION OF SOLID WASTE HANDLING: FRACTION TO SHARU	FRAC TO HAMILTON LANDFILL	FRAC TO BURLINGTON LANDFILL	FRAC TO APARTMENT INCINERAT.	FRACTION TO AIR	FRACTION TO ASH	DECAY FACTOR IN LANDFILL	HAMILTON: FRACTION TO LANDFILL DIRECT	FRACTION TO LEACHATE SHARU or APT. INC.	FRAC TO BURLINGTON LEACHATE	FRACTION OF LANDFILL LEACHATE EACH HAMILTON	TRANSPORTED YEAR BURLINGTON	Kd (cc/gm) in HAMILTON	SOURCE
H3		1							1							
C14		1							1							
P32		1							0.056							
P33		1							0.1							
S35		1							0.34							
CrS1		1							0.11							
Co57	4.00E+07	1			1				0.87			1		1	1000	lake sediments
Ni63	7.00E+07	1			1				1			1		1	2	lake sediments
Ni63	1.00E+09	1	1				0.01	0.99	1		0.1		1		2	e- capture detector
Zn65	2.00E+07	1			1				0.098			1		1	10	lake sediments
Ga67		0.8							0.013							
Se75																
Tc99m		0.25							0.001							
I125		1							0.24							
I131		0.96							0.033							
Tl201		0.9							0.012							
Po210	1.00E+09	1	0.6	0.2	0.2		0.01	0.99	0.55	0.0001	0.1	0.0001	0.01	1	1000	anti static devices
Am241	6.40E+08	1	0.56	0.19	0.21	0.04	0.01	0.99	1	0.0001	0.1	0.0001	0.0001	1	3000	smoke detectors

TABLE 6.7

LOADINGS AND CONCENTRATIONS

RADIO-ISOTOPES	MASS FROM HAM-BURL COLLECTED (Bq/a)	LOADING TO LANDFILL (Bq/a)	LOADING TO SHARU (Bq/a)	LOADING DIRECT TO HAMILTON LANDFILL (Bq/a)	LOADING DIRECT TO BURLINGTON LANDFILL (Bq/a)	CONC. TO GARBAGE WORKER HAMILTON Bq/cc	CONC. TO GARBAGE WORKER BURLINGTON Bq/cc	CONC. INCINER. FEED Bq/cc	STACK RELEASE Bq/s	MASS TO SHARU ASH (Bq/a)	CONC. OF SHARU ASH Bq/cc	MASS TO APT. INC. ASH (Bq/a)	MASS TO HAMILTON LANDFILL (Bq/a)	MASS TO BURLINGTON LANDFILL (Bq/a)	HAMILTON LANDFILL CONC. Bq/m3	BURLINGTON LANDFILL CONC. Bq/m3	HAMILTON EXPOSURE CONC. TO LANDFILL WORKER Bq/cc	BURLINGTON EXPOSURE CONC. TO LANDFILL WORKER Bq/cc
H3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
P32	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
P33	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
S35	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CrS1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co57	4.00E+07	4.00E+07	0.00E+00	0.00E+00	4.00E+07	0.00E+00	5.56E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E+07	0.00E+00	1.93E+02	0.00E+00	1.93E-04
Ni63	7.00E+07	7.00E+07	0.00E+00	0.00E+00	7.00E+07	0.00E+00	9.72E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E+07	0.00E+00	3.89E+02	0.00E+00	3.89E-04
Ni63	1.00E+09	1.00E+09	1.00E+09	0.00E+00	0.00E+00	2.78E-04	0.00E+00	2.78E-04	3.16E-01	9.90E+08	3.67E-03	0.00E+00	9.90E+08	0.00E+00	1.65E+03	0.00E+00	1.65E-03	0.00E+00
Zn65	2.00E+07	2.00E+07	0.00E+00	0.00E+00	2.00E+07	0.00E+00	2.78E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E+07	0.00E+00	1.09E+01	0.00E+00	1.09E-05
Ga67	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Se75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tc99m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I125	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I131	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl201	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po210	1.00E+09	1.00E+09	6.00E+08	2.00E+08	2.00E+08	2.22E-04	2.78E-04	2.22E-04	1.90E-01	5.94E+08	2.20E-03	0.00E+00	7.94E+08	2.00E+08	7.28E+02	6.11E+02	7.28E-04	6.11E-04
Am241	6.40E+08	6.40E+08	3.58E+08	1.22E+08	1.34E+08	1.33E-04	1.87E-04	1.33E-04	1.13E-01	3.55E+08	1.31E-03	2.56E+07	5.02E+08	1.34E+08	8.37E+02	7.47E+02	8.37E-04	7.47E-04

NOTE: COMPUTER - B:TABLE7.1

1 2 3 4 5 6 7 8 9 10 11

54 TABLE 6.8:

55 CALCULATING SEEPAGE MASS FLOW FROM HAMILTON LANDFILL TO HAMILTON HARBOUR (VIA RED HILL CR.)

56

57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79
		RADIO-	ISOTOPE		H3	C14	P32	P33	S35	Cr51	Co57	Ni63	Ni63	Zn65	Ga67	Se75	Tc99m	I125	I131	Tl201	Po210	Am241
POTENTIAL LEACHATE DIRECT APPLICAT.	Bq/a				0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E+04	1.22E+04
POTENTIAL LEACHATE FROM INCINER.	Bq/a				0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.90E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.94E+07	3.80E+07
POTENTIAL LANDFILL LEACHATE CONC.	Bq/m3				0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.65E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.45E+01	6.34E+01
ACTUAL LANDFILL LEACHATE CONC.	Bq/m3				0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.94E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.45E-02	5.64E-03
MASS FLOW TO HAMILTON HARBOUR	Bq/a				0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.85E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.63E+00	1.41E-02

80

81 TABLE 6.9:

82 CALCULATING SEEPAGE MASS FLOW FROM BURLINGTON LANDFILL TO BURLINGTON WWTP

83

84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106
		RADIO-	ISOTOPE		H3	C14	P32	P33	S35	Cr51	Co57	Ni63	Ni63	Zn65	Ga67	Se75	Tc99m	I125	I131	Tl201	Po210	Am241
MASS FLOW TO LANDFIL BURLINGTON	Bq/a				0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E+07	7.02E+07	0.00E+00	2.00E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E+08	1.34E+08
LANDFILL CONC.	Bq/m3				0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.93E+02	3.90E+02	0.00E+00	1.09E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.11E+02	7.47E+02
POTENTIAL LEACHATE CONC.	Bq/m3				0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.93E+02	3.90E+02	0.00E+00	1.09E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.11E-02	7.47E-02
ACTUAL LEACHATE CONC.	Bq/m3				0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.15E-02	4.59E+01	0.00E+00	2.83E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.62E-05	6.64E-06
MASS FLOW TO BURL. WWTP	Bq/a				0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.29E+03	1.15E+06	0.00E+00	7.07E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.07E-01	1.66E-01
EXPOSURE CONC. TO LANDFILL WORKER	Bq/cc				0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.93E-04	3.90E-04	0.00E+00	1.09E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.11E-04	7.47E-04
EXPOSURE CONC. IN DUST	Bq/cc				0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.93E-04	3.90E-04	0.00E+00	1.09E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.11E-08	7.47E-08
LOADING TO LANDFILL FROM WWTP (TABLE 6108)	Bq/yr				0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.25E+02	2.29E+05		1.07E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.87E-01	1.50E-01

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108 NOTE: COMPUTER - B:TABLE7 (rows 54-108 only)

TABLE G.10A

BURLINGTON WWTP PARTITION FACTORS

	1	2	3	4	5	6	7	8	9	10	11	12	13
								WWTP SLUDGE STREAM					
		SEEPAGE											
		MASS FLOW			WWTP LIQUID STREAM				SLUDGE		DIGESTER		
	RADIO-	FROM	LOADING TO	LOSS IN	FRACTION	FRAC TO	LOSS TO	FRAC TO	LOSS TO	FRAC TO	FRACTION	LOSS TO	FRAC TO
	ISOTOPE	LANDFILL	SEWER	SEWER	TO AIR	SLUDGE	DECAY	EFFLUENT	DECAY	EFFLUENT	TO AIR	DECAY	LANDFILL
		(Bq/a)	(Bq/a)										
H3		0.00E+00			4.40E-01								
C14		0.00E+00	2.00E+09	0.00E+00		4.89E-01		4.89E-01			7.60E-01		2.40E-01
P32		0.00E+00											
P33		0.00E+00											
S35		0.00E+00											
Cr51		0.00E+00											
Co57		1.29E+03				1.00E-01		9.00E-01		1.00E+00		3.00E-02	9.70E-01
Ni63		1.15E+06				2.00E-01		8.00E-01		1.00E+00			1.00E+00
Zn65		7.07E+04				2.00E-01		8.00E-01		1.00E+00		2.40E-01	7.60E-01
Ga67		0.00E+00					5.20E-02						
Se75		0.00E+00											
Tc99m		0.00E+00					7.33E-01		1.00E+00				
I125		0.00E+00											
I131		0.00E+00											
Tl201		0.00E+00					5.50E-02		8.95E-01				
Po210		4.07E-01				9.50E-01		5.00E-02		1.00E+00			1.00E+00
Am241		1.66E-01				9.50E-01		5.00E-02		1.00E+00		5.00E-02	9.50E-01

TABLE G.10B

BURLINGTON WWTP CALCULATIONS (SEWER SYSTEM AND LANDFILL LOADINGS)

RADIO-ISOTOPE	LOADING TO WWTP (Bq/a)	MASS FLOW EFFLUENT (Bq/a)	MASS FLOW EFFLUENT Bq/s	MASS FLOW SLUDGE (Bq/a)	MASS FLOW TO DIGEST SLUDGE (Bq/a)	AIR MASS FLOW AERATOR (Bq/a)	CONCENTRAT IN FLOW DIGESTER (Bq/a)	CONC. AERATOR Is Bq/cc	CONC. SLUDGE TO LAND Bq/cc	DIGESTER RELEASE Bq/s	LOADING TO LANDFILL FROM WWTP (Bq/a)
H3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C14	2.00E+09	9.78E+08	3.09E+01	9.78E+08	0.00E+00	0.00E+00	0.00E+00	1.75E-05	0.00E+00	0.00E+00	0.00E+00
P32	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
P33	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
S35	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cr51	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co57	1.29E+03	1.16E+03	3.67E-05	1.29E+02	1.29E+02	0.00E+00	1.29E+02	1.15E-11	5.66E-17	4.08E-06	1.25E+02
Ni63	1.15E+06	9.18E+05	2.91E-02	2.30E+05	2.30E+05	0.00E+00	2.30E+05	1.02E-08	1.01E-13	7.26E-03	2.30E+05
Zn65	7.07E+04	5.66E+04	1.79E-03	1.41E+04	1.41E+04	0.00E+00	1.41E+04	6.31E-10	6.22E-15	4.48E-04	1.07E+04
Ga67	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Se75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tc99m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I125	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I131	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl201	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po210	4.07E-01	2.04E-02	6.44E-10	3.87E-01	3.87E-01	0.00E+00	3.87E-01	3.64E-15	1.70E-19	1.22E-08	3.87E-01
Am241	1.66E-01	8.30E-03	2.63E-10	1.58E-01	1.58E-01	0.00E+00	1.58E-01	1.48E-15	6.93E-20	4.99E-09	1.50E-01

NOTE: COMPUTER - B:TABLE10

TABLE G11: SURFACE WATER CALCULATIONS

RADIO-ISOTOPE	HAMILTON WWTP TO H.H. Bq/a	BURLINGTON WWTP TO H.H. Bq/a	HAMILTON LANDFILL TO H.H. Bq/a	INPUT HAMILTON HARBOUR Bq/a	C/Co HAMILTON HARBOUR	CONC TO LAKE ONTARIO Bq/a	CONCENTRAT HAMILTON HARBOUR Bq/m3	(C/Co) L.O.	CONCENTRAT WATER INTAKE Bq/m3	FRACTION REMOVED WTP	CONCENTRAT DRINKING WATER Bq/L
H3	1.00E+08	0.00E+00	0.00E+00	1.00E+08	9.90E-01	9.90E+07	4.50E-02	7.00E-01	3.15E-02	6.00E-01	1.26E-05
C14	4.20E+08	9.78E+08	0.00E+00	1.40E+09	1.00E+00	1.40E+09	6.35E-01	7.00E-01	4.45E-01	0.00E+00	4.45E-04
P32	3.00E+08	0.00E+00	0.00E+00	3.00E+08	8.40E-01	2.52E+08	1.15E-01	7.00E-01	8.02E-02	7.50E-01	2.00E-05
P33	0.00E+00	0.00E+00	0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	7.50E-01	0.00E+00
S35	1.32E+09	0.00E+00	0.00E+00	1.32E+09	7.30E-01	9.64E+08	4.38E-01	7.00E-01	3.07E-01	0.00E+00	3.07E-04
Cr51	2.31E+09	0.00E+00	0.00E+00	2.31E+09	4.20E-01	9.70E+08	4.41E-01	7.00E-01	3.09E-01	9.00E-01	3.09E-05
Co57	1.80E+03	1.16E+03	0.00E+00	2.96E+03	8.20E-01	2.43E+03	1.10E-06	7.00E-01	7.72E-07	5.00E-01	3.86E-10
Ni63	0.00E+00	9.18E+05	4.85E+05	1.40E+06	1.00E+00	1.40E+06	6.38E-04	7.00E-01	4.47E-04	5.00E-01	2.23E-07
Zn65	0.00E+00	5.66E+04	0.00E+00	5.66E+04	2.40E-01	1.36E+04	6.17E-06	7.00E-01	4.32E-06	4.00E-01	2.59E-09
Ga67	5.16E+10	0.00E+00	0.00E+00	5.16E+10	9.20E-02	4.75E+09	2.16E+00	6.80E-01	1.47E+00	9.00E-01	1.47E-04
Se75	0.00E+00	0.00E+00	0.00E+00	0.00E+00		0.00E+00	0.00E+00	7.00E-01	0.00E+00	0.00E+00	0.00E+00
Tc99m	5.87E+11	0.00E+00	0.00E+00	5.87E+11	7.50E-03	4.40E+09	2.00E+00	5.30E-01	1.06E+00	7.50E-01	2.65E-04
I125	2.80E+10	0.00E+00	0.00E+00	2.80E+10	1.00E+00	2.80E+10	1.27E+01	7.00E-01	8.91E+00	0.00E+00	8.91E-03
I131	8.00E+10	0.00E+00	0.00E+00	8.00E+10	1.00E+00	8.00E+10	3.64E+01	7.00E-01	2.55E+01	0.00E+00	2.55E-02
Tl201	4.89E+10	0.00E+00	0.00E+00	4.89E+10	8.60E-02	4.21E+09	1.91E+00	6.80E-01	1.30E+00	0.00E+00	1.30E-03
Po210	0.00E+00	2.04E-02	3.63E+00	3.65E+00	7.80E-01	2.85E+00	1.29E-09	7.00E-01	9.06E-10	0.00E+00	9.06E-13
Am241	0.00E+00	8.30E-03	1.41E-02	2.24E-02	9.70E-01	2.17E-02	9.87E-12	7.00E-01	6.91E-12	9.00E-01	6.91E-16

COMPUTER -B:AECBHAM5 (rows 1-2 7 only)

TABLE 6.12

FACTORS FOR LIQUID RADIOISOTOPES ACCIDENTLY DISPOSED TO SOLID WASTE AT HAMILTON HOSPITALS

HAMILTON

RADIO-ISOTOPE	ANNUAL LOADING TO SOLID WASTE (Bq/a)	DECAY FACTOR IN COLLECTION	DIRECTION OF SOLID WASTE HANDLING: FRAC. TO SWARU	DIRECTION OF SOLID WASTE HANDLING: FRAC. TO HAMILTON LANDFILL	SWARU: FRACTION TO AIR	SWARU: FRACTION TO ASH	DECAY FACTOR IN LANDFILL	FRACTION TO LEACHATE: LANDFILL DIRECT	FRACTION TO LEACHATE: SWARU OR APT. INCTR	FRAC TO BURLINGTON LEACHATE	FRACTION OF LANDFILL LEACHATE TRANSPORTED: EACH HAMILTON YEAR	FRACTION OF LANDFILL LEACHATE TRANSPORTED: EACH BURLINGTON YEAR	SOURCE
H3	2.00E+06	1.00E+00	7.50E-01	2.50E-01	1.00E+00		1.00E+00	1.00E+00	1.00E+00		1.00E-02		accidental loss liquid waste
C14	2.50E+06	1.90E+00	7.50E-01	2.50E-01	1.00E+00		1.00E+00	1.00E+00	1.00E+00		1.00E-02		accidental loss liquid waste
P32	3.00E+06	1.00E+00	7.50E-01	2.50E-01	1.00E-02	9.90E-01	5.60E-02	1.00E+00	1.00E+00		1.00E-02		accidental loss liquid waste
P33		1.00E+00					1.00E-01	1.00E+00	1.00E+00		1.00E-02		
S35	1.50E+06	1.00E+00	7.50E-01	2.50E-01	1.00E-02	9.90E-01	3.40E-01	1.00E+00	1.00E+00		1.00E-02		accidental loss liquid waste
Cr51	3.00E+06	1.00E+00	7.50E-01	2.50E-01	1.00E-02	9.90E-01	1.10E-01	1.00E+00	1.00E+00		1.00E-02		accidental loss liquid waste
Co57	3.00E+01	1.00E+00	7.50E-01	2.50E-01	1.00E-02	9.90E-01	8.70E-01	1.00E+00	1.00E+00		1.00E-02		accidental loss liquid waste
Ni63		1.00E+00					1.00E+00	1.00E+00	1.00E+00		1.00E-02		
Zn65		1.90E+00					9.80E-02	1.00E+00	1.00E+00		1.00E-02		
Ga67	7.70E+07	8.00E-01	7.50E-01	2.50E-01	1.00E-02	9.90E-01	1.30E-02	1.00E+00	1.00E+00		1.00E-02		accidental loss liquid waste
Se75								1.00E+00	1.00E+00		1.00E-02		
Tc99m	2.10E+10	2.50E-01	7.50E-01	2.50E-01	1.00E-02	9.90E-01	1.00E-03	1.00E+00	1.00E+00		1.00E-02		accidental loss liquid waste
I125	2.80E+07	1.00E+00	7.50E-01	2.50E-01	1.00E-02	9.90E-01	2.40E-01	1.00E+00	1.00E+00		1.00E-02		accidental loss liquid waste
I131	8.00E+07	9.60E-01	7.50E-01	2.50E-01	1.00E-02	9.90E-01	3.30E-02	1.00E+00	1.00E+00		1.00E-02		accidental loss liquid waste
Tl201	5.80E+07	9.00E-01	7.50E-01	2.50E-01	1.00E-02	9.90E-01	1.20E-02	1.00E+00	1.00E+00		1.00E-02		accidental loss liquid waste
Po210		1.00E+00					5.50E-01	1.00E+00	1.00E+00		1.00E-02		
Am241							1.00E+00	1.00E+00	1.00E+00		1.00E-02		

TABLE 6.13

DOSE TO SOLID WASTE WORKERS FROM ACCIDENTAL SPILL

RADIO-ISOTOPE	MASS FLOW TO BE DISPOSED (Bq/a)	CONC. TO GARBAGE WORKER (Bq/cc)	MASS TO SWARU ASH (Bq/a)	MASS DIRECT TO LANDFILL (Bq/a)	CONC. TO SWARU ASH LOADER (Bq/cc)	EXPOSURE CONC. TO LANDFILL WORKER (Bq/cc)	DOSE TO TRUCK DRIVER: DCFt	DOSE TO TRUCK DRIVER: (Sv/a/p)	DCFi	DCFe	DCFg	DOSE FROM GARBAGE (Sv/a/p)	CONC. IN AIR Bq/m3	E9r (Sv/a/p)	DOSE FROM EXTERNAL CLOUD INMERS E9r (Sv/a/p)	TOTAL DOSE TO LANDFILL WORKER (Sv/a/p)
H3	2.00E+06	5.56E-07	0.00E+00	5.00E+05	0.00E+00	8.33E-07	0.00E+00	0.00E+00	4.00E-11	0.00E+00	0.00E+00	0.00E+00	1.11E-10	1.07E-17	0.00E+00	1.07E-17
C14	2.50E+06	6.94E-07	0.00E+00	6.25E+05	0.00E+00	1.04E-06	0.00E+00	0.00E+00	5.20E-12	0.00E+00	0.00E+00	0.00E+00	1.39E-10	1.73E-18	0.00E+00	1.73E-18
P32	3.00E+06	8.33E-07	2.23E+06	7.50E+05	8.25E-06	2.78E-07	0.00E+00	0.00E+00	4.40E-09	0.00E+00	0.00E+00	0.00E+00	1.67E-10	1.76E-15	0.00E+00	1.76E-15
P33	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.80E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
S35	1.50E+06	4.17E-07	1.11E+06	3.75E+05	4.13E-06	8.44E-07	0.00E+00	0.00E+00	7.80E-10	0.00E+00	0.00E+00	0.00E+00	8.33E-11	1.56E-16	0.00E+00	1.56E-16
Cr51	3.00E+06	8.33E-07	2.23E+06	7.50E+05	8.25E-06	5.46E-07	1.20E-09	1.50E-12	1.00E-10	4.27E-08	3.70E-09	6.17E-12	1.67E-10	4.00E-17	1.62E-18	6.17E-12
Co57	2.00E+01	5.56E-12	1.49E+01	5.00E+00	5.50E-11	2.80E-11	3.20E-08	2.67E-16	2.90E-09	1.72E-07	1.10E-08	1.22E-16	1.11E-15	7.73E-21	4.36E-23	1.22E-16
Ni63	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.20E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zn65	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-07	0.00E+00	5.70E-09	8.17E-07	7.90E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ga67	6.16E+07	1.71E-05	4.57E+07	1.54E+07	1.69E-04	1.32E-06	4.30E-08	1.10E-09	1.50E-10	1.99E-07	1.70E-08	5.82E-10	3.42E-09	1.23E-15	1.55E-16	5.82E-10
Se75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-07	0.00E+00	2.10E-09	5.30E-07	4.00E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tc99m	5.25E+09	1.46E-03	3.90E+09	1.31E+09	1.44E-02	6.68E-06	3.30E-08	7.22E-08	7.90E-12	1.80E-07	1.20E-08	3.50E-08	2.92E-07	5.53E-15	1.20E-14	3.50E-08
I125	2.80E+07	7.78E-06	2.00E+07	7.00E+06	7.70E-05	1.11E-05	2.70E-11	3.15E-13	9.30E-09	1.50E-08	1.50E-10	2.33E-12	1.56E-09	3.47E-14	5.32E-18	2.37E-12
I131	7.68E+07	2.13E-05	5.70E+07	1.92E+07	2.11E-04	4.19E-06	1.40E-07	4.48E-09	1.10E-08	5.17E-07	5.30E-08	2.26E-09	4.27E-09	1.13E-13	5.03E-16	2.26E-09
Tl201	5.22E+07	1.45E-05	3.80E+07	1.31E+07	1.44E-04	1.04E-06	5.60E-10	1.22E-11	5.90E-11	2.40E-08	1.70E-09	4.93E-11	2.90E-09	4.11E-16	1.59E-17	4.93E-11
Po210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.50E-06	1.19E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Am241	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-09	0.00E+00	1.30E-04	2.57E-08	1.70E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

NOTE: COMPUTER - B:TABLE12

TOTAL DOSE 7.78E-08

TOTAL DOSE TO GARBAGE AND TRANS STAT WORKERS 3.79E-08

TOTAL DOSE TO LANDFILL WORKER 3.79E-08

APPENDIX H

Dosimetry Calculation Spreadsheets

TABLE W.1: COLLECTIVE DOSE FROM ATMOSPHERIC RELEASES

RADIO-ISOTPE	WASTE STREAM	Ts(a) Bq/s	Ps1 s/m3	I1 Bq/m3	P12 m	I2 Bq/m2	(DCF)i Sv/Bq	P15i Sv/a/Bq/m2	(DCF)e Sv/a/Bq/m2	P15e Sv/a/Bq/m2	(DCF)g Sv/a/Bq/m2	P29 Sv/a/Bq/m2	I9 Sv/a/pers	I9POP Sv./a	DIGESTER RELEASE Bq/s	TABLE G7 C10-SF 0.00E+00	AIR MASS FLOW AERATOR (Bq/a)	62-C15 STACK RELEASE Bq/s	62-C15 LOSS TO AIR VIA AERATOR Bq/s
H3	2A	3.23E+01	4.60E-08	1.48E-06	0.00E+00	0.00E+00	2.00E-11	1.68E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.49E-13	1.31E-07	0.00E+00	0.00E+00	0.00E+00	3.23E+01	2.70E+01
H3	2B	2.70E+01	5.50E-07	1.53E-05	0.00E+00	0.00E+00	2.00E-11	1.68E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.57E-12	1.35E-06	0.00E+00	0.00E+00	0.00E+00	2.53E+00	0.00E+00
C14	2A	2.53E+00	4.60E-08	1.16E-07	0.00E+00	0.00E+00	5.20E-12	4.37E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.03E-15	2.67E-09	0.00E+00	0.00E+00	0.00E+00	8.54E-01	0.00E+00
P32	2A	8.54E-01	4.60E-08	3.93E-08	1.78E+04	7.00E-04	4.40E-09	3.70E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.45E-12	7.63E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
P33		0.00E+00	4.60E-08	0.00E+00	1.79E+04	0.00E+00	6.80E-10	5.71E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.70E-02	0.00E+00
S35	2A	5.70E-02	4.60E-08	2.62E-09	1.09E+05	2.86E-04	7.80E-10	6.55E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.72E-14	9.01E-09	0.00E+00	0.00E+00	0.00E+00	2.18E-01	0.00E+00
Cr51	2A	2.18E-01	4.60E-08	1.00E-08	3.47E+04	3.49E-04	1.00E-10	8.40E-07	4.27E-08	3.42E-08	9.21E-10	3.35E-10	1.26E-13	6.60E-08	4.08E-06	0.00E+00	0.00E+00	6.14E-08	0.00E+00
Co57	2A	6.14E-08	4.60E-08	2.82E-15	2.73E+05	7.71E-10	2.90E-09	2.44E-05	1.72E-07	1.38E-07	3.87E-09	1.41E-09	1.16E-18	6.06E-13	7.24E-03	3.16E-01	0.00E+00	0.00E+00	0.00E+00
Ni63	3	3.16E-01	4.60E-08	1.46E-08	2.53E+07	3.68E-01	5.20E-10	4.37E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.36E-14	3.34E-08	4.48E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zn65		0.09E+00	4.60E-08	0.00E+00	3.02E+05	0.00E+00	5.70E-09	4.79E-05	8.17E-07	6.54E-07	1.48E-08	5.39E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.15E-01	0.00E+00
Ga67	2A	5.15E-01	4.60E-08	2.37E-08	4.05E+03	9.60E-05	1.50E-10	1.26E-06	1.99E-07	1.59E-07	4.42E-09	1.61E-09	1.88E-13	9.87E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Se75	2A	0.00E+00	4.60E-08	0.00E+00	1.49E+05	0.00E+00	2.10E-09	1.76E-05	5.30E-07	4.24E-07	1.16E-08	4.22E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.25E-22	0.00E+00
Tc99	2A	1.25E-22	4.60E-08	5.77E-30	3.12E+02	1.60E-27	7.90E-12	6.64E-08	1.80E-07	1.44E-07	3.99E-09	1.45E-09	3.83E-26	2.01E-20	0.00E+00	0.00E+00	0.00E+00	2.22E-03	0.00E+00
I125	2A	2.22E-03	4.60E-08	1.02E-10	7.49E+04	7.63E-06	9.30E-09	7.81E-05	1.50E-08	1.20E-08	6.68E-10	2.43E-10	9.82E-15	5.15E-09	0.00E+00	0.00E+00	0.00E+00	6.33E-03	0.00E+00
I131	2A	6.33E-03	4.60E-08	2.91E-10	1.00E+04	2.91E-06	1.10E-08	9.24E-05	5.17E-07	4.14E-07	1.09E-08	3.97E-09	3.86E-14	2.03E-08	0.00E+00	0.00E+00	0.00E+00	1.01E-04	0.00E+00
Tl201	2A	1.01E-04	4.60E-08	8.32E-12	3.84E+03	3.20E-08	5.90E-11	4.96E-07	2.40E-08	1.92E-08	5.40E-10	1.97E-10	1.06E-17	5.55E-12	0.00E+00	0.00E+00	0.00E+00	1.90E-01	0.00E+00
Po210	3	1.90E-01	4.60E-08	8.73E-09	1.71E+05	1.49E-03	2.50E-06	2.10E-02	1.19E-11	9.52E-12	2.33E-13	8.48E-14	1.83E-10	9.63E-05	1.22E-08	1.90E-01	0.00E+00	0.00E+00	0.00E+00
Am241	3	1.13E-01	4.60E-08	5.22E-09	3.70E+07	1.93E-01	1.30E-04	1.09E+00	2.57E-08	2.06E-08	8.08E-10	2.94E-10	5.75E-09	3.02E-03	4.99E-03	1.13E-01	0.00E+00	0.00E+00	0.00E+00
											TOTAL:		each	3.12E-03 population (525,000)					

NOTE:

1-landfill

2-STP a) incinerator/digester

b) aeration tanks

3-SWARU

COMPUTER -B:AECBNAME

TABLE H.2: DOSE FROM ATMOSPHERIC RELEASES--CRITICAL GROUP IN GENERAL POPULATION

RADIO-ISOTOPE	WASTE STREAM	Is(a) Bq/s	Psi s/m3	Ii Bq/m3	Pi3 m	Ii3 Bq/m2	DCF(i)(Ad)	P19(i)(Ad)	DCF(i)(In)	P19(i)(In)	DCF(e)	P19(e)	DCF(g)	P39	I9(Adult) Sv/a/p	I9(infant) Sv/a/p
H3	2A	3.23E+01	1.10E-06	3.55E-05	0.00E+00	0.00E+00	2.00E-11	1.68E-07	5.80E-11	8.12E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.97E-12	2.88E-12
	2B	2.78E+01	1.20E-05	3.34E-04	0.00E+00	0.00E+00	2.00E-11	1.68E-07	5.80E-11	8.12E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.61E-11	2.71E-11
C14	2A	2.53E+00	1.10E-06	2.78E-06	0.00E+00	0.00E+00	5.20E-12	4.37E-08	1.50E-11	2.10E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.22E-13	5.85E-14
P32	2A	8.54E-01	1.10E-06	9.40E-07	1.78E+04	1.67E-02	4.40E-09	3.70E-05	2.00E-08	9.80E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.47E-11	2.63E-11
P33		0.00E+00	1.10E-06	0.00E+00	1.79E+04	0.00E+00	6.8E-10	5.71E-06	2.7E-09	3.70E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
S35	2A	5.70E-02	1.10E-06	6.27E-08	1.09E+05	6.83E-03	7.80E-10	6.55E-06	2.60E-09	3.64E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.11E-13	2.28E-13
Cr51	2A	2.10E-01	1.10E-06	2.40E-07	3.47E+04	8.33E-03	1.00E-10	8.40E-07	3.80E-10	5.32E-07	4.27E-08	3.42E-08	9.21E-10	3.35E-10	3.00E-12	2.93E-12
Co57	2A	6.14E-08	1.10E-06	6.75E-14	2.73E+05	1.84E-08	2.90E-09	2.44E-05	8.20E-09	1.15E-05	1.72E-07	1.38E-07	3.87E-09	1.41E-09	2.76E-17	2.68E-17
Ni63	3	3.16E-01	1.10E-06	3.48E-07	2.53E+07	3.81E+00	5.20E-10	4.37E-06	1.60E-09	2.24E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.52E-12	7.80E-13
In65		0.00E+00	1.10E-06	0.00E+00	3.02E+05	0.00E+00	5.7E-09	4.79E-05	1.3E-08	1.82E-05	8.17E-07	6.54E-07	1.48E-08	5.39E-09	0.00E+00	0.00E+00
Ga67	2A	5.15E-01	1.10E-06	5.67E-07	4.05E+03	2.30E-03	1.50E-10	1.26E-06	4.80E-10	6.72E-07	1.99E-07	1.59E-07	4.42E-09	1.61E-09	4.50E-12	4.16E-12
Se75		0.00E+00	1.10E-06	0.00E+00	1.49E+05	0.00E+00	2.1E-09	1.76E-05	4.7E-09	6.58E-06	5.3E-07	4.24E-07	1.16E-08	4.22E-09	0.00E+00	0.00E+00
Tc99	2A	1.25E-22	1.10E-06	1.38E-28	3.12E+02	4.31E-26	7.90E-12	6.64E-08	4.10E-11	5.74E-08	1.80E-07	1.44E-07	3.99E-09	1.45E-09	9.16E-35	9.03E-35
I125	2A	2.22E-03	1.10E-06	2.44E-09	7.49E+04	1.83E-04	9.30E-09	7.81E-05	3.60E-08	5.04E-05	1.50E-08	1.20E-08	6.68E-10	2.43E-10	2.35E-13	1.67E-13
I131	2A	6.33E-03	1.10E-06	6.96E-09	1.00E+04	6.96E-05	1.10E-08	9.24E-05	8.70E-08	1.22E-04	5.17E-07	4.14E-07	1.09E-08	3.97E-09	9.22E-13	1.13E-12
Tl201	2A	1.81E-04	1.10E-06	1.99E-10	3.84E+03	7.64E-07	5.90E-11	4.96E-07	2.70E-10	3.78E-07	2.40E-08	1.92E-08	5.40E-10	1.97E-10	2.53E-16	2.29E-16
Po210	3	1.90E-01	1.10E-06	2.09E-07	1.71E+05	3.57E-02	2.50E-06	2.10E-02	6.90E-06	9.66E-03	1.19E-11	9.52E-12	2.33E-13	8.48E-14	4.39E-09	2.02E-09
Am241	3	1.13E-01	1.10E-06	1.25E-07	3.70E+07	4.62E+00	1.30E-04	1.09E+00	1.20E-03	1.68E+00	2.57E-08	2.06E-08	8.08E-10	2.94E-10	1.38E-07	2.11E-07
													TOTAL:		1.42E-07 each	2.13E-07 each

NOTE:

1-landfill

2-STP A) incinerator

B)aeration tanks COMPUTER -B:AECDWAM3

3-SWARU

TABLE H.3

DOSE FROM AQUATIC RELEASES - COLLECTIVE AND CRITICAL GROUP IN GENERAL POPULATION

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
		LOADING															COLLECTIVE	INDIVIDUAL
RADIO-	WASTE	TO H.H.	Ps2(B)	I2(B)	Ps2(H)	I2(H)	P26	I6	DCF(i)Ad	P29(i)(Ad)	DCF(i)inf	P29(i)inf	P69(ad)**	P69(inf)**	ISCRITad	ISCRIinf	ISPOP	I9 POP
ISOTOPE	STREAM	Bq/s	s/l	Bq/l	s/l	Bq/l	l/kg	Bq/kg	Sv/Bq	Sv/a/Bq/l	Sv/Bq	Sv/a/Bq/l	Sv/Bq/kg	Sv/a/Bq/kg	Sv/a/p	Sv/a/p	Sv/a	Sv/a/p
H3	2	3.16E+00	3.98E-06	1.26E-05	1.42E-05	4.50E-05	1.00E+00	4.50E-05	2.00E-11	1.40E-08	5.00E-11	5.22E-09	1.10E-10	3.48E-11	1.81E-13	6.72E-14	9.26E-08	1.76E-13
C14	2	4.44E+01	1.00E-05	4.45E-04	1.43E-05	6.35E-04	5.00E+03	3.18E+00	5.20E-10	3.64E-07	1.60E-09	1.44E-07	2.86E-09	9.60E-10	9.25E-09	3.11E-09	8.50E-05	1.62E-10
P32	2	9.52E+00	2.10E-06	2.00E-05	1.20E-05	1.15E-04	1.00E+05	1.15E+01	2.30E-09	1.61E-06	1.30E-08	1.17E-06	1.27E-08	7.80E-09	1.45E-07	8.94E-08	1.69E-05	3.23E-11
P33	2	0.00E+00	0.00E+00	6.13E-11	0.00E+00	2.45E-10	1.00E+05	2.45E-05	2.40E-10	1.68E-07	1.20E-09	1.08E-07	1.32E-09	7.20E-10	3.24E-14	1.76E-14	5.40E-12	1.03E-17
S35	2	4.19E+01	7.32E-06	3.07E-04	1.05E-05	4.30E-04	3.00E+02	1.31E-01	2.00E-10	1.40E-07	4.90E-10	4.41E-08	1.10E-09	2.94E-10	1.87E-10	5.22E-11	2.25E-05	4.29E-11
Cr51	2	7.33E+01	4.21E-07	3.09E-05	6.01E-06	4.41E-04	2.00E+02	8.82E-02	3.30E-11	2.31E-08	6.90E-11	6.21E-09	1.02E-10	4.14E-11	1.67E-11	3.84E-12	3.74E-07	7.13E-13
Co57	2	9.40E-05	4.11E-06	3.86E-10	1.17E-05	1.10E-09	1.00E+02	1.10E-07	5.40E-10	3.78E-07	1.70E-09	1.53E-07	2.97E-09	1.02E-09	4.74E-16	1.72E-16	7.66E-11	1.46E-16
Ni63	2	4.45E-02	5.01E-06	2.23E-07	1.43E-05	6.37E-07	4.00E+01	2.55E-05	1.10E-10	7.70E-08	2.20E-10	1.98E-08	6.05E-10	1.32E-10	3.26E-14	7.77E-15	3.01E-09	1.72E-14
Zn65	1	1.80E-04	1.44E-06	2.59E-10	3.44E-06	6.17E-10	2.00E+03	1.23E-06	4.00E-09	2.80E-06	1.00E-08	9.00E-07	2.20E-08	6.00E-09	2.79E-14	7.64E-15	3.81E-10	7.26E-16
Ga67	2	1.64E+03	8.96E-08	1.47E-04	1.32E-06	2.16E-03	2.00E+01	4.32E-02	1.90E-10	1.33E-07	2.70E-10	2.43E-08	1.05E-09	1.62E-10	6.46E-11	1.06E-11	1.02E-05	1.95E-11
Se75		0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E+02	0.00E+00	2.60E-09	1.82E-06	6.10E-09	5.49E-07	1.43E-08	3.66E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tc99m	2	1.86E+04	7.11E-09	1.32E-04	1.07E-07	2.00E-03	3.00E+01	6.00E-02	1.70E-11	1.19E-08	8.10E-11	7.29E-09	9.35E-11	4.86E-11	7.19E-12	3.88E-12	8.28E-07	1.58E-12
I125	2	8.89E+02	1.00E-05	8.91E-03	1.43E-05	1.27E-02	5.00E+01	6.36E-01	9.30E-09	6.51E-06	3.60E-08	3.24E-06	5.12E-08	2.16E-08	9.05E-08	4.26E-08	3.04E-02	5.80E-08
I131	2	2.54E+03	1.00E-05	2.55E-02	1.43E-05	3.64E-02	5.00E+01	1.82E+00	1.10E-08	7.70E-06	8.70E-08	7.83E-06	6.05E-08	5.22E-08	3.06E-07	2.94E-07	4.03E-01	1.96E-07
Tl201	2	1.55E+03	8.37E-07	1.30E-03	1.23E-06	1.91E-03	1.00E+05	1.91E+02	7.60E-11	5.32E-08	3.20E-10	2.88E-08	4.18E-10	1.92E-10	8.01E-08	3.68E-08	3.63E-05	6.92E-11
Po210	1	1.16E-07	7.82E-06	9.06E-13	1.12E-05	1.29E-12	5.00E+01	6.47E-11	5.30E-07	3.71E-04	8.00E-07	7.20E-05	2.92E-06	4.80E-07	5.25E-16	9.63E-17	1.76E-10	3.36E-16
Am241	1	7.11E-10	9.72E-07	6.91E-16	1.39E-05	9.87E-15	3.00E+01	2.96E-13	6.00E-07	4.20E-04	5.40E-06	4.86E-04	3.30E-06	3.24E-06	1.27E-18	1.30E-18	1.52E-13	2.90E-19
													TOTAL:		6.31E-07	4.66E-07	1.34E-01	2.54E-07
																	population	each
																	(525,000)	

NOTE: 1-landfill * assumed COMPUTER -B:AECDWAMS (rows 29- 57 only)
2 - STP
3 - SWARU ** fish co

TABLE H.4A:

ANNUAL COMMITTED DOSE (Sv/a) TO VARIOUS WORKERS:

SLUDGE WORKER - STP HAMILTON

RADIOISOTOPE	DCFi	DCFe	DCF-DD	DCF-SS	DCF-G	MASS FLOW TO SLUDGE	X1	CONC. TO SLUDGE FILTERS	X9i	X9e	X9DD	X9SS	X9G	X9TOTAL
	Sv/a/Bq/m3	Sv/a/Bq/m3	Sv/h/Bq/cc	Sv/h/Bq/cc	Sv/h/Bq/cc	Bq/a	Bq/m3	Bq/cc	Sv/a/p	Sv/a/p	Sv/a/p	Sv/a/p	Sv/a/p	Sv/a/p
H3	4.00E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.02E+09	1.92E-02	3.33E-03	1.84E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.84E-09
C14	5.20E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E+07	1.50E-03	2.67E-04	1.87E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.87E-11
P32	4.40E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.70E+09	5.07E-02	3.75E-02	5.35E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.35E-07
P33	6.80E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
S35	7.80E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E+08	3.38E-03	2.50E-03	6.33E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.33E-09
Cr51	1.00E-10	4.27E-08	2.50E-11	2.80E-11	5.30E-10	6.90E+08	1.30E-02	9.58E-03	3.11E-09	1.26E-10	2.40E-10	2.68E-10	1.02E-08	1.39E-08
Co57	2.90E-09	1.27E-07	8.90E-10	7.30E-10	2.20E-09	2.00E+02	3.76E-09	2.69E-09	2.61E-14	1.09E-16	2.40E-15	1.97E-15	1.19E-14	4.25E-14
Ni63	5.20E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zn65	5.70E-09	8.17E-07	2.50E-09	4.60E-09	8.90E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ga67	1.50E-10	1.99E-07	1.10E-09	9.00E-10	2.50E-09	1.38E+10	2.59E-01	2.26E-02	9.33E-08	1.18E-08	2.49E-08	2.04E-08	1.13E-07	2.63E-07
Se75	2.10E-09	5.30E-07	4.80E-09	4.50E-09	6.50E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tc99m	7.90E-12	1.80E-07	8.60E-10	7.30E-10	2.30E-09	4.79E+11	8.99E+00	5.51E-24	1.70E-07	3.70E-07	4.74E-30	4.02E-30	2.53E-29	5.40E-07
I125	9.30E-09	1.50E-08	1.20E-12	5.20E-10	3.80E-10	7.00E+06	1.31E-04	9.72E-05	2.93E-09	4.50E-13	1.17E-13	5.06E-11	7.39E-11	3.06E-09
I131	1.10E-08	5.17E-07	2.90E-09	3.40E-09	6.30E-09	2.00E+07	3.76E-04	2.78E-04	9.92E-09	4.43E-11	8.06E-10	9.44E-10	3.50E-09	1.52E-08
Tl201	5.90E-11	2.40E-08	1.40E-11	1.30E-11	3.00E-10	5.19E+07	9.74E-04	7.94E-06	1.38E-10	5.34E-12	1.11E-13	1.03E-13	4.76E-12	1.48E-10
Po210	2.50E-06	1.19E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Am241	1.30E-04	2.57E-08	6.00E-11	3.90E-11	4.50E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
													TOTAL:	1.38E-06

1 2 3 4 5 6 7 8 9 10

25 TABLE H4D:SLUDGE WORKER BURLINGTON STP

26

27 CONC.

28 MASS FLOW SLUDGE

29 RADIOISOTOPE SLUDGE TO LAND I1 I9i I9e I9DD I9SS I9G I9TOTAL

30 (Bq/a) Bq/cc Bq/m3 Sv/a/p Sv/a/p Sv/a/p Sv/a/p Sv/a/p Sv/a/p

31 H3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
32 C14	9.78E+08	0.00E+00	1.84E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
33 P32	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
34 P33	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
35 S35	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
36 Cr51	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
37 Co57	1.29E+02	5.66E-17	2.42E-09	3.94E-22	7.09E-17	5.04E-23	4.13E-23	2.49E-22	7.09E-17
38 Ni63	2.30E+05	1.01E-13	4.31E-06	1.26E-19	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.26E-19
39 Zn65	1.41E+04	6.22E-15	2.66E-07	8.50E-20	5.01E-14	1.55E-20	2.86E-20	1.11E-19	5.01E-14
40 Ga67	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
41 Se75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
42 Tc99m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
43 I125	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
44 I131	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
45 Tl201	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
46 Po210	3.87E-01	1.70E-19	7.27E-12	1.02E-21	1.99E-23	0.00E+00	0.00E+00	0.00E+00	1.04E-21
47 Am241	1.58E-01	6.93E-20	2.96E-12	2.16E-20	1.75E-20	4.16E-27	2.70E-27	6.23E-25	3.92E-20

48

49

50 TOTAL: 5.01E-14

51

52 NOTE:

53 Dose Conversion Factors:

54 DCFi=(Sv/a)/(Bq/m3) inhalation

55 DCFe=(Sv/a)/(Bq/m3) external cloud immersion

56 DCFDD=(Sv/h)/(Bq/cm3) gamma from dewatering drum

57 DCFSS=(Sv/h)/(Bq/cm3) gamma from sludge slurry tank

58 DCFG=(SV/h)/(Bq/cm3) gamma from sludge on floor

59 concentrations: I1-in air (Bq/m3)

60 ISL-in sludge (Bq/m3)

I9 doses: i-inhalation

(Sv/a) e-cloud immersion

DD-dewatering drum

SS-slurry tank

G-sludge on floor (ground)

COMPUTER -B:ACDSW

	1	2	3	4	5	6	7	8	9	10
1	TABLE H.5 A:HAMILTON									
2	ANNUAL COMMITTED DOSE (Sv/a):									
3	AERATION WORKER - STP					CONC.				
4						AERATOR				
5	RADIOISOTOPE	DCFi	DCFe	DCFa	Il	Is	I9i	I9e	I9a	I9TOTAL
6		Sv/Bq	Sv/a/Bq/m3	Sv/h/Bq/cc	Bq/m3	Bq/cc	Sv/a	Sv/a	Sv/a	Sv/a
7	H3	4.00E-11	0.00E+00	0.00E+00	1.00E-04	1.00E-05	3.60E-12	0.00E+00	0.00E+00	3.60E-12
8	C14	5.20E-12	0.00E+00	0.00E+00	4.46E-05	4.46E-06	2.09E-13	0.00E+00	0.00E+00	2.09E-13
9	P32	4.40E-09	0.00E+00	0.00E+00	2.68E-04	2.68E-05	1.06E-09	0.00E+00	0.00E+00	1.06E-09
10	P33	6.80E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	S35	7.80E-10	0.00E+00	0.00E+00	1.34E-04	1.34E-05	9.40E-11	0.00E+00	0.00E+00	9.40E-11
12	Cr51	1.00E-10	4.27E-08	4.27E-08	2.68E-04	2.68E-05	2.41E-11	9.79E-13	8.58E-10	8.83E-10
13	Co57	2.90E-09	1.72E-07	1.72E-07	1.79E-10	1.79E-11	4.66E-16	2.63E-18	2.30E-15	2.77E-15
14	Ni63	5.20E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	Zn65	5.70E-09	8.17E-07	8.17E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
16	Ga67	1.50E-10	1.99E-07	1.99E-07	5.84E-03	5.84E-04	7.88E-10	9.95E-11	8.72E-08	8.80E-08
17	Se75	2.10E-09	5.30E-07	5.30E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
18	Tc99m	7.90E-12	1.80E-07	1.80E-07	5.24E-02	5.24E-03	3.72E-10	8.07E-10	7.07E-07	7.08E-07
19	I125	9.30E-09	1.50E-08	1.50E-08	2.50E-03	2.50E-04	2.09E-08	3.21E-12	2.81E-09	2.37E-08
20	I131	1.10E-08	5.17E-07	5.17E-07	7.14E-03	7.14E-04	7.07E-08	3.16E-10	2.77E-07	3.48E-07
21	Tl201	5.90E-11	2.40E-08	2.40E-08	4.37E-03	4.37E-04	2.32E-10	8.98E-12	7.87E-09	8.11E-09
22	Po210	2.50E-06	1.19E-11	1.19E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
23	Am241	1.30E-04	2.57E-08	2.57E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
24	TABLE H5B: BURLINGTON								TOTAL	1.17E-06
25		CONC IN	CONC IN							
26	RADIOISOTOPE	SEWAGE	AIR	I9i	I9e	I9a	TOTAL I9			
27		Bq/cc	Bq/m3	Sv/a/p	Sv/a/p	Sv/a/p	Sv/a/p			
28	H3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			
29	C14	1.75E-05	1.75E-04	8.17E-13	0.00E+00	0.00E+00	8.17E-13			
30	P32	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			
31	P33	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			
32	S35	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			
33	Cr51	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			
34	Co57	1.15E-11	1.15E-10	3.00E-16	1.69E-19	1.48E-15	1.78E-15			
35	Ni63	1.02E-08	1.02E-07	4.80E-14	0.00E+00	0.00E+00	4.80E-14			
36	Zn65	6.31E-10	6.31E-09	3.24E-14	4.42E-17	3.87E-13	4.19E-13			
37	Ga67	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			
38	Se75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			
39	Tc99m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			
40	I125	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			
41	I131	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			
42	Tl201	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			
43	Po210	3.64E-15	3.64E-14	8.18E-17	3.71E-27	3.25E-23	8.18E-17			
44	Am241	1.48E-15	1.48E-14	1.73E-15	3.26E-24	2.86E-20	1.73E-15			
45						TOTAL	1.29E-12			
46										
47	NOTE:							I9 doses: i-inhalation		
48	Dose Conversion Factors:							e-cloud immersion		
49	DCFe=(Sv/a)/(Bq/m3) external cloud immersion							I9a-aeration tanks		
50	DCFa=(SV/a)/(Bq/m3) gamma from aeration tanks									
51	DCFi=(Sv/Bq) inhalation									
52								COMPUTER -B:ACDAM		
53	concentrations: Il-in air (Bq/m3)									
54	Is-in sewage (Bq/m3)									

TABLE H.6

ANNUAL COMMITTED DOSE (Sv/a) :

ASH LOADER - STP

RADIOISOTOPE	DCFi	DCFe	DCFg	STP INC. DECAY FACTOR	Ii	Ia	Ia'	I9i	I9e	I9g	I9TOTAL
H3	4.00E-11	0.00E+00	0.00E+00	1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C14	5.20E-12	0.00E+00	0.00E+00	1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
P32	4.40E-09	0.00E+00	0.00E+00	0.85	9.56E-06	5.63E-02	4.78E-02	1.26E-11	0.00E+00	0.00E+00	1.26E-11
P33	6.80E-10	0.00E+00	0.00E+00		0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
S35	7.80E-10	0.00E+00	0.00E+00	1	2.67E-06	1.34E-02	1.34E-02	6.25E-13	0.00E+00	0.00E+00	6.25E-13
Cr51	1.00E-10	4.27E-08	2.10E-09	0.9	1.02E-05	5.69E-02	5.12E-02	3.07E-13	1.25E-14	2.99E-08	2.99E-08
Co57	2.90E-09	1.27E-07	8.80E-09	1	3.20E-12	1.60E-08	1.60E-08	2.78E-18	1.16E-20	3.52E-14	3.52E-14
Ni63	5.20E-10	0.00E+00	0.00E+00	1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zn65	5.70E-09	8.17E-07	3.40E-08	0.91	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ga67	1.50E-10	1.99E-07	1.00E-08	0.52	7.06E-06	6.78E-02	3.53E-02	3.18E-13	4.00E-14	1.70E-07	1.70E-07
Se75	2.10E-09	5.30E-07	9.70E-08	1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tc99m	7.90E-12	1.80E-07	9.10E-09	0.051	1.69E-29	1.65E-24	8.43E-26	3.99E-38	8.64E-38	3.76E-30	3.76E-30
I125	9.30E-09	1.50E-08	1.50E-09	1	1.16E-07	5.78E-04	5.78E-04	3.22E-13	4.94E-17	2.17E-10	2.17E-10
I131	1.10E-08	5.17E-07	2.50E-08	0.76	1.90E-07	1.25E-03	9.50E-04	6.27E-13	2.80E-15	7.81E-09	7.81E-09
I120I	5.90E-11	2.40E-08	1.20E-09	0.5	2.38E-09	2.38E-05	1.19E-05	4.22E-17	1.63E-18	7.15E-12	7.15E-12
Po210	2.50E-06	1.19E-11	0.00E+00	1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Am241	1.30E-04	2.57E-08	1.80E-09	1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
						TOTAL:		1.48E-11	5.53E-14	2.08E-07	2.08E-07

NOTE:

Dose Conversion Factors:

DCFi=(Sv/Bq) inhalation

DCFe=(Sv/a)/(Bq/m3) external cloud immersion

DCFg=(SV/h)/(Bq/cm2) gamma from ash on ground

concentrations: Ii-in air (Bq/m3)

Ia-in ash (Bq/cm3)

Ia'-after decay in storage pit

I9 doses: i-inhalation

e-cloud immersion

g-ash on ground

COMPUTER -B:ACBALSTP

TABLE H.7

ANNUAL COMMITTED DOSE (Sv/a) TO:

TRUCK DRIVER - STP WWTP INC.

RADIOISOTOPE	DCFi	DCFe	DCFt	DCFg	Ii	FACTOR DECAY	Ia'	Ia	I9i	I9e	I9t	I9g	I9TOTAL
H3	4.00E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C14	5.20E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
P32	4.40E-09	0.00E+00	0.00E+00	0.00E+00	1.13E-05	0.85	4.78E-02	5.63E-02	2.97E-11	0.00E+00	0.00E+00	0.00E+00	2.97E-11
P33	6.80E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00		0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
S35	7.80E-10	0.00E+00	0.00E+00	0.00E+00	2.67E-06	1	1.34E-02	1.34E-02	1.25E-12	0.00E+00	0.00E+00	0.00E+00	1.25E-12
Cr51	1.00E-10	4.27E-08	1.80E-10	2.10E-09	1.14E-05	0.9	5.12E-02	5.69E-02	6.83E-13	2.77E-14	5.12E-09	1.49E-09	2.01E-08
Co57	2.30E-09	1.72E-07	4.30E-03	8.80E-09	3.20E-12	1	1.60E-08	1.60E-08	5.57E-15	3.14E-20	3.92E-08	1.76E-14	3.92E-08
Ni63	5.20E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zn65	5.70E-09	8.17E-07	2.90E-08	3.40E-08	0.00E+00	0.91	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sr87	1.50E-10	1.93E-07	6.50E-09	1.00E-08	1.36E-05	0.52	3.53E-02	6.78E-02	1.22E-11	1.54E-13	1.20E-07	8.49E-08	3.05E-07
Se75	2.10E-09	5.30E-07	3.10E-08	2.60E-08	0.00E+00	1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tc99m	7.90E-12	1.80E-07	5.00E-09	9.10E-09	3.30E-28	0.051	8.43E-26	1.65E-24	1.57E-30	3.23E-28	4.12E-30	1.88E-30	6.01E-30
I125	3.20E-09	1.50E-08	3.70E-12	1.50E-09	1.16E-07	1	5.78E-04	5.78E-04	6.44E-13	9.89E-17	1.07E-11	1.08E-10	1.10E-10
I131	1.10E-08	5.17E-07	2.20E-08	2.50E-08	2.50E-07	0.76	9.50E-04	1.25E-03	1.65E-12	7.38E-15	1.32E-08	3.91E-09	1.77E-08
Tl201	5.90E-11	2.40E-08	8.40E-11	1.20E-09	4.76E-09	0.5	1.19E-05	2.38E-05	1.69E-16	6.52E-18	1.00E-12	3.57E-12	4.57E-12
Po210	2.50E-06	1.19E-11	0.00E+00	0.00E+00	0.00E+00	1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Am241	1.20E-04	2.57E-08	2.60E-10	1.80E-09	0.00E+00	1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
							TOTAL:		3.51E-11	1.89E-13	2.78E-07	1.94E-07	1.62E-07

NOTE:

Dose Conversion Factors:

DCFi=(Sv/Bq) inhalation

DCFe=(Sv/a)/(Bq/m3) external cloud immersion

DCFt=(Sv/h)/(Bq/cm3) gamma from ash in truck

DCFg=(SV/h)/(Bq/m3) gamma from ash on ground

concentrations: Ii-in air (Bq/m3)

Ia-in ash (Bq/cm3)

Ia'-after decay in storage pit

I9 doses: i-inhalation

(Sv/a) e-cloud immersion

t-ash in truck

g-ash on ground

COMPUTER -B:ACDTDSTP

1 2 3 4 5 6

TABLE H8: ANNUAL COMMITTED DOSE TO GARBAGE TRUCK DRIVERS
IN HAMILTON (R 5-27) AND BURLINGTON (R 29-60)

HAMILTON:

RADIO-ISOTOPE	DCFt	CONCENTRAT GARBAGE Bq/cc	I9 Sv/p/a
H3	0.00E+00	0.00E+00	0.00E+00
C14	0.00E+00	0.00E+00	0.00E+00
P32	0.00E+00	0.00E+00	0.00E+00
P33	0.00E+00	0.00E+00	0.00E+00
S35	0.00E+00	0.00E+00	0.00E+00
Cr51	1.20E-09	0.00E+00	0.00E+00
Co57	3.20E-08	0.00E+00	0.00E+00
Ni63	0.00E+00	2.78E-04	0.00E+00
Zn65	1.90E-07	0.00E+00	0.00E+00
Ga67	4.30E-08	0.00E+00	0.00E+00
Se75	2.00E-07	0.00E+00	0.00E+00
Tc99m	3.30E-08	0.00E+00	0.00E+00
I125	2.70E-11	0.00E+00	0.00E+00
I131	1.40E-07	0.00E+00	0.00E+00
Tl201	5.60E-10	0.00E+00	0.00E+00
Po210	0.00E+00	2.22E-04	0.00E+00
Am241	1.80E-09	1.33E-04	3.60E-10
		TOTAL:	3.60E-10

BURLINGTON:

RADIO-ISOTOPE	DCFt	CONCENTRAT GARBAGE Bq/cc	I9 Sv/p/a
H3	0.00E+00	0.00E+00	0.00E+00
C14	0.00E+00	0.00E+00	0.00E+00
P32	0.00E+00	0.00E+00	0.00E+00
P33	0.00E+00	0.00E+00	0.00E+00
S35	0.00E+00	0.00E+00	0.00E+00
Cr51	1.20E-09	0.00E+00	0.00E+00
Co57	3.20E-08	5.56E-05	2.67E-09
Ni63	0.00E+00	9.72E-05	0.00E+00
Zn65	1.90E-07	2.78E-05	7.92E-09
Ga67	4.30E-08	0.00E+00	0.00E+00
Se75	2.00E-07	0.00E+00	0.00E+00
Tc99m	3.30E-08	0.00E+00	0.00E+00
I125	2.70E-11	0.00E+00	0.00E+00
I131	1.40E-07	0.00E+00	0.00E+00
Tl201	5.60E-10	0.00E+00	0.00E+00
Po210	0.00E+00	2.78E-04	0.00E+00
Am241	1.80E-09	1.87E-04	5.04E-10
		TOTAL:	1.11E-08

NOTE: DCFt = DOSE CONVERSION FACTOR GARBAGE IN TRUCK
I9 = DOSE (Sv/p/a)
COLUMN 7 FOR DUPLICATE Ni63
COMPUTER CODE = H8

TABLE H9: ANNUAL COMMITTED DOSE TO GARBAGE COLLECTORS IN HAMILTON (R 5-27) AND BURLINGTON (R 29-60)

HAMILTON:

RADIO-ISOTOPE	DCFg	CONCENTRAT GARBAGE Bq/cc	DOSE Sv/p/a
H3	0.00E+00	0.00E+00	0.00E+00
C14	0.00E+00	0.00E+00	0.00E+00
P32	0.00E+00	0.00E+00	0.00E+00
P33	0.00E+00	0.00E+00	0.00E+00
S35	0.00E+00	0.00E+00	0.00E+00
Cr51	1.10E-09	0.00E+00	0.00E+00
Co57	3.00E-08	0.00E+00	0.00E+00
Ni63	0.00E+00	2.78E-04	0.00E+00
Zn65	1.60E-07	0.00E+00	0.00E+00
Ga67	3.80E-08	0.00E+00	0.00E+00
Se75	1.80E-07	0.00E+00	0.00E+00
Tc99m	3.00E-08	0.00E+00	0.00E+00
I125	2.30E-11	0.00E+00	0.00E+00
I131	1.30E-07	0.00E+00	0.00E+00
Tl201	5.00E-10	0.00E+00	0.00E+00
Po210	0.00E+00	2.22E-04	0.00E+00
Am241	1.60E-09	1.33E-04	3.20E-10
		TOTAL:	3.20E-10

BURLINGTON:

RADIO-ISOTOPE	DCFg	CONCENTRAT GARBAGE Bq/cc	DOSE Sv/p/a
H3	0.00E+00	0.00E+00	0.00E+00
C14	0.00E+00	0.00E+00	0.00E+00
P32	0.00E+00	0.00E+00	0.00E+00
P33	0.00E+00	0.00E+00	0.00E+00
S35	0.00E+00	0.00E+00	0.00E+00
Cr51	1.10E-09	0.00E+00	0.00E+00
Co57	3.00E-08	5.56E-05	2.50E-09
Ni63	0.00E+00	9.72E-05	0.00E+00
Zn65	1.60E-07	2.78E-05	6.67E-09
Ga67	3.80E-08	0.00E+00	0.00E+00
Se75	1.80E-07	0.00E+00	0.00E+00
Tc99m	3.00E-08	0.00E+00	0.00E+00
I125	2.30E-11	0.00E+00	0.00E+00
I131	1.30E-07	0.00E+00	0.00E+00
Tl201	5.00E-10	0.00E+00	0.00E+00
Po210	0.00E+00	2.78E-04	0.00E+00
Am241	1.60E-09	1.87E-04	4.48E-10
		TOTAL:	9.61E-09

NOTE: DCFg = DOSE CONVERSION FACTOR GARBAGE

COMPUTER CODE = B:H9

TABLE H10: ANNUAL COMMITTED DOSE TO TRUCK DRIVER
AT HAMILTON TRANFER STATION

RADIO-ISOTOPE	DCFt	CONCENTRAT GARBAGE Bq/cc	DOSE Sv/p/a
H3	0.00E+00	0.00E+00	0.00E+00
C14	0.00E+00	0.00E+00	0.00E+00
P32	0.00E+00	0.00E+00	0.00E+00
P33	0.00E+00	0.00E+00	0.00E+00
S35	0.00E+00	0.00E+00	0.00E+00
Cr51	1.20E-09	0.00E+00	0.00E+00
Co57	3.20E-08	0.00E+00	0.00E+00
Ni63	0.00E+00	2.78E-04	0.00E+00
Zn65	1.90E-07	0.00E+00	0.00E+00
Ga67	4.30E-08	0.00E+00	0.00E+00
Se75	2.00E-07	0.00E+00	0.00E+00
Tc99m	3.30E-08	0.00E+00	0.00E+00
I125	2.70E-11	0.00E+00	0.00E+00
I131	1.40E-07	0.00E+00	0.00E+00
Tl201	5.60E-10	0.00E+00	0.00E+00
Po210	0.00E+00	2.22E-04	0.00E+00
Am241	1.80E-09	1.33E-04	3.60E-10
		TOTAL:	3.60E-10

NOTE: DCFt = DOSE CONVERSION FACTOR FOR GARBAGE IN TRUCK

COMPUTER CODE = B:H10

TABLE H11: ANNUAL COMMITTED DOSE TO LANDFILL SITE WORKERS

A: HAMILTON

RADIO-ISOTOPES	DCFi Sv/Bq	DCFe Sv/a/Bq/m3	DCFg Sv/a/Bq/cc	CONCENTRAT IN AIR Bq/m3	CONCENTRAT GARBAGE Bq/cc	DOSE INHALED Sv/a/p	Ie Sv/a/p	Ig Sv/a/p	I9 Sv/a/p
H3	4.00E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C14	5.20E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
P32	4.40E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
P33	6.80E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
S35	7.80E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cr51	1.00E-10	4.27E-08	3.70E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co57	2.90E-09	1.72E-07	1.10E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni63	5.20E-10	0.00E+00	0.00E+00	1.67E-07	2.78E-04	1.04E-13	0.00E+00	0.00E+00	1.04E-13
Zn65	5.70E-09	8.17E-07	7.90E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ga67	1.50E-10	1.99E-07	1.70E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Se75	2.10E-09	5.30E-07	4.00E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tc99m	7.90E-12	1.80E-07	1.20E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I125	9.30E-09	1.50E-08	1.50E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I131	1.10E-08	5.17E-07	5.30E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl201	5.90E-11	2.40E-08	1.70E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po210	2.50E-06	1.19E-11	0.00E+00	1.33E-07	2.22E-04	4.00E-10	3.62E-19	0.00E+00	4.00E-10
Am241	1.30E-04	2.57E-08	1.70E-09	8.00E-08	1.33E-04	1.25E-08	4.69E-16	4.53E-10	1.29E-08
								TOTAL:	1.33E-08

B: BURLINGTON

RADIO-ISOTOPE	DCFi Sv/Bq	DCFe Sv/a/Bq/m3	DCFg Sv/h/Bq/cc	CONC AIR Bq/m3	CONC GARBAGE Bq/cc	Ii Sv/a/p	Ie Sv/a/p	Ig Sv/a/p	I9 Sv/a/p
H3	4.00E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C14	5.20E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
P32	4.40E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
P33	6.80E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
S35	7.80E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cr51	1.00E-10	4.27E-08	3.70E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co57	2.90E-09	1.72E-07	1.10E-08	3.33E-08	5.56E-05	1.16E-13	1.31E-15	1.22E-09	1.22E-09
Ni63	5.20E-10	0.00E+00	0.00E+00	5.83E-08	9.72E-05	3.64E-14	0.00E+00	0.00E+00	3.64E-14
Zn65	5.70E-09	8.17E-07	7.90E-08	1.67E-08	2.78E-05	1.14E-13	3.11E-15	4.39E-09	4.39E-09
Ga67	1.50E-10	1.99E-07	1.70E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Se75	2.10E-09	5.30E-07	4.00E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tc99m	7.90E-12	1.80E-07	1.20E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I125	9.30E-09	1.50E-08	1.50E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I131	1.10E-08	5.17E-07	5.30E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl201	5.90E-11	2.40E-08	1.70E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po210	2.50E-06	1.19E-11	0.00E+00	1.67E-07	2.78E-04	5.00E-10	4.53E-19	0.00E+00	5.00E-10
Am241	1.30E-04	2.57E-08	1.70E-09	1.12E-07	1.87E-04	1.75E-08	6.57E-16	6.35E-10	1.81E-08
								TOTAL:	2.42E-08

NOTE: DOSE CONVERSION FACTORS
- DCFi -INHALATION
- DCFe -EXTERNAL CLOUD IMMERSION
- DCFg -GAMMA FROM GARBAGE

DOSES:
- Ii -INHALED
- Ie -EXTERNAL CLOUD
- Ig -GAMMA

COMPUTER CODE = B:H

TABLE H12: ANNUAL COMMITTED DOSE TO LOADER AT SWARU INCINERATOR (HAMILTON)

RADIO-ISOTOPE	DCFi Sv/Bq	DCFe Sv/a/Bq/m3	DCFa Sv/h/Bq/cc	DCFag Sv/h/Bq/cc	CONC AIR INDOORS Bq/m3	CONC AIR OUTSIDE Bq/m3	CONC ASH Bq/cc	DOSE INHALED Sv/a/p	DOSE EXTERNAL CLOUD Sv/a/p	DOSE ASH IN PIT Sv/a/p	DOSE ASH ON GROUND Sv/a/p	TOTAL DOSE Sv/a/p
H3	4.00E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C14	5.20E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
P32	4.40E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
P33	6.80E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
S35	7.80E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cr51	1.00E-10	4.27E-08	5.80E-10	2.10E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co57	2.90E-09	1.72E-07	1.50E-08	8.80E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni63	5.20E-10	0.00E+00	0.00E+00	0.00E+00	3.67E-07	7.33E-07	3.67E-03	5.72E-13	0.00E+00	0.00E+00	0.00E+00	5.72E-13
Zn65	5.70E-09	8.17E-07	9.70E-08	3.40E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ga67	1.50E-10	1.99E-07	2.00E-08	1.00E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Se75	2.10E-09	5.30E-07	9.70E-08	3.10E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tc99m	7.90E-12	1.80E-07	1.50E-08	9.10E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I125	9.30E-09	1.50E-08	1.10E-11	1.50E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I131	1.10E-08	5.17E-07	7.10E-08	2.50E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl201	5.90E-11	2.40E-08	2.60E-10	1.20E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po210	2.50E-06	1.19E-11	0.00E+00	0.00E+00	2.20E-07	4.40E-07	2.20E-03	1.65E-09	7.44E-19	0.00E+00	0.00E+00	1.65E-09
Am241	1.30E-04	2.57E-08	7.80E-10	1.89E-09	1.31E-07	2.63E-07	1.31E-03	5.13E-08	9.59E-16	1.54E-09	1.24E-09	5.40E-08
											TOTAL:	5.57E-08

NOTE: DOSE CONVERSION FACTORS:

DCFi = INHALED

DCFe= CLOUD IMMERSION

DCFg= GAMMA FROM ASH PIT

DCFag = GAMMA FROM ASH ON GROUND

COMPUTER CODE : B:H12

TABLE H13: ANNUAL COMMITTED DOSE TO TRUCK DRIVERS AT SWARU

RADIO-ISOTOPE	DCFi Sv/Bq	DCFe Sv/a/Bq/m3	DCFt Sv/h/Bq/cc	DCFag Sv/h/Bq/cc	CONC IN AIR Bq/m3	CONC IN ASH Bq/cc	DOSE INHALED Sv/a/p	DOSE EXTERNAL CLOUD Sv/a/p	DOSE ASH IN TRUCK Sv/a/p	DOSE ASH ON GROUND Sv/a/p	TOTAL DOSE Sv/a/p
H3	4.00E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C14	5.20E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
P32	4.40E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
P33	6.80E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
S35	7.80E-10	0.00E+00	0.00E+00	2.10E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cr51	1.00E-10	4.27E-08	1.80E-10	8.80E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co57	2.90E-09	1.72E-07	4.90E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni63	5.20E-10	0.00E+00	0.00E+00	3.40E-08	7.33E-07	3.67E-03	4.58E-13	0.00E+00	0.00E+00	3.12E-08	3.12E-08
Zn65	5.70E-09	8.17E-07	2.90E-08	1.00E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ga67	1.50E-10	1.99E-07	6.50E-09	3.10E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Se75	2.10E-09	5.30E-07	2.60E-08	9.10E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tc99m	7.90E-12	1.80E-07	5.00E-09	1.50E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I125	9.30E-09	1.50E-08	3.70E-12	2.50E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I131	1.10E-08	5.17E-07	2.20E-08	1.20E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl201	5.90E-11	2.40E-08	8.40E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po210	2.50E-06	1.19E-11	0.00E+00	1.89E-09	4.40E-07	2.20E-03	1.32E-09	5.24E-15	0.00E+00	1.04E-09	2.36E-09
Am241	1.30E-04	2.57E-08	2.60E-10	7.80E-10	2.63E-07	1.31E-03	4.10E-08	6.75E-12	3.42E-10	2.56E-10	4.16E-08
										TOTAL:	7.51E-08

NOTE: DOSE CONVERSION FACTORS
DCFi = INHALED
DCFe = EXTERNAL CLOUD
DCFt = ASH IN TRUCK
DCFag = ASH ON GROUND

COMPUTER CODE B:H13

TABLE H14: ANNUAL COMMITTED DOSE TO SORTER AT SWARU

RADIO-ISOTOPE	DCFi Sv/Bq	DCFe Sv/a/Bq/m3	DCFso Sv/h/Bq/cc	CONC SWARU ASH Bq/cc	CONC IN AIR INDOORS Bq/m3	CONC IN GARBAGE Bq/cc	DOSE INHALED Sv/a/p	DOSE EXTERNAL CLOUD Sv/a/p	DOSE GARBAGE Sv/a/p	TOTAL DOSE Sv/a/p
H3	4.00E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C14	5.20E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
P32	4.40E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
P33	6.80E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
S35	7.80E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cr51	1.00E-10	4.27E-08	5.20E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co57	2.90E-09	1.72E-07	2.20E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni63	5.20E-10	0.00E+00	0.00E+00	3.67E-03	3.67E-07	2.78E-04	4.58E-13	0.00E+00	0.00E+00	4.58E-13
Zn65	5.70E-09	8.17E-07	8.40E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ga67	1.50E-10	1.99E-07	2.50E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Se75	2.10E-09	5.30E-07	6.60E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tc99m	7.90E-12	1.80E-07	2.30E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I125	9.30E-09	1.50E-08	3.80E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I131	1.10E-08	5.17E-07	6.20E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl201	5.90E-11	2.40E-08	3.10E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po210	2.50E-06	1.19E-11	0.00E+00	2.20E-03	2.20E-07	2.22E-04	1.32E-09	5.24E-15	0.00E+00	1.32E-09
Am241	1.30E-04	2.57E-08	4.60E-08	1.31E-03	1.31E-07	1.33E-04	4.10E-08	6.75E-12	1.23E-08	5.33E-08
									TOTAL:	5.46E-08

NOTE: DOSE CONVERSION FACTORS
DCFi = INHALED
DCFe = EXTERNAL CLOUD
DCFso = GARBAGE ON SORTING LINE

COLUMNS 13 & 14
TO ACCOMODATE DUPLICATE Ni-63 VALUES

COMPUTER CODE : B:H14

1 2 3 4 5 6 7 8

TABLE H15: ANNUAL COMMITTED DOSE TO LOADERS AT TRANSFER STATION (HAMILTON)

RADIO-ISOTOPE	DCFgp Sv/h/Bq/cc	CONC IN GARBAGE Bq/cc	TOTAL DOSE Sv/a/p
H3	0.00E+00	0.00E+00	0.00E+00
C14	0.00E+00	0.00E+00	0.00E+00
P32	0.00E+00	0.00E+00	0.00E+00
P33	0.00E+00	0.00E+00	0.00E+00
S35	0.00E+00	0.00E+00	0.00E+00
Cr51	5.80E-09	0.00E+00	0.00E+00
Co57	1.50E-07	0.00E+00	0.00E+00
Ni63	0.00E+00	2.78E-04	0.00E+00
Zn65	9.70E-07	0.00E+00	0.00E+00
Ga67	2.00E-07	0.00E+00	0.00E+00
Se75	9.70E-07	0.00E+00	0.00E+00
Tc99m	1.50E-07	0.00E+00	0.00E+00
I125	1.10E-10	0.00E+00	0.00E+00
I131	7.10E-07	0.00E+00	0.00E+00
Tl201	2.60E-09	0.00E+00	0.00E+00
Po210	0.00E+00	2.22E-04	0.00E+00
Am241	7.80E-09	1.33E-04	2.08E-09
		TOTAL:	2.08E-09

NOTE: DCFgp = DOSE CONVERSION FACTOR GARBAGE PILE

COMPUTER CODE : B:H15

APPENDIX I

Sensitivity Analysis

SENSITIVITY ANALYSIS

To test the sensitivity of the model to changes in source terms, a "credible accident" scenario was modelled for Hamilton. This assumed that Hamilton Hospital laboratories disposed of 10% of their annual inventory of radioisotopes in the solid waste going to municipal disposal. This basically assumes a lot of spills, etc., which are wiped up and the cleaning cloths thrown in with the general laboratory garbage.

The annual source terms used in this analysis compare to those assumed for normal laboratory operation as follows (Bq/a):

Radioisotope	Normal (Table G7)	Accident (Table G12)
H-3	0	2.00E6
C-14	0	2.50E6
P-32	0	3.00E6
P-33	0	0
S-35	0	1.50E6
Cr-51	0	3.00E6
Co-57	4.00E7	2.00E1
Ni-63	1.00E9	0
Zn-65	2.00E7	0
Ga-67	0	7.70E7
Se-75	0	0
Tc-99m	0	2.10E10
I-125	0	2.80E7
I-131	0	8.00E7
Tl-201	0	5.80E7
Po-210	1.00E9	0
Am-241	6.40E8	0

Based on this accident scenario, a dose to landfill workers of 3.79E-8 Sv/a/p or 38 uSv/a/p was calculated (Table G13). When added to the calculated dose to landfill workers from normal garbage (71.3 uSv/a/p) and the per capita dose from living in the

TABLE 6.12

FACTORS FOR LIQUID RADIOISOTOPES ACCIDENTLY DISPOSED TO SOLID WASTE AT HAMILTON HOSPITALS

RADIO-ISOTOPE	ANNUAL LOADING TO SOLID WASTE (Bq/a)	DECAY FACTOR IN COLLECTION	DIRECTION OF SOLID WASTE HANDLING: FRAC. TO SHARU	FRAC. TO HAMILTON LANDFILL	SHARU: FRACTION TO AIR	SHARU: FRACTION TO ASH	DECAY FACTOR IN LANDFILL	HAMILTON: FRACTION TO LEACHATE LANDFILL DIRECT	SHARU OR APT. INCIN	FRAC TO BURLINGTON LEACHATE	FRACTION OF LANDFILL LEACHATE TRANSPORTED EACH YEAR: HAMILTON	BURLINGTON	SOURCE
H3	2.00E+06	1.00E+00	7.50E-01	2.50E-01	1.00E+00		1.00E+00	1.00E+00	1.00E+00		1.00E-02		accidental loss liquid waste
C14	2.50E+06	1.00E+00	7.50E-01	2.50E-01	1.00E+00		1.00E+00	1.00E+00	1.00E+00		1.00E-02		accidental loss liquid waste
P32	3.00E+06	1.00E+00	7.50E-01	2.50E-01	1.00E-02	9.90E-01	5.60E-02	1.00E+00	1.00E+00		1.00E-02		accidental loss liquid waste
P33		1.00E+00					1.00E-01	1.00E+00	1.00E+00		1.00E-02		
S35	1.50E+06	1.00E+00	7.50E-01	2.50E-01	1.00E-02	9.90E-01	3.40E-01	1.00E+00	1.00E+00		1.00E-02		accidental loss liquid waste
Cr51	3.00E+06	1.00E+00	7.50E-01	2.50E-01	1.00E-02	9.90E-01	1.10E-01	1.00E+00	1.00E+00		1.00E-02		accidental loss liquid waste
Co57	2.00E+01	1.00E+00	7.50E-01	2.50E-01	1.00E-02	9.90E-01	8.70E-01	1.00E+00	1.00E+00		1.00E-02		accidental loss liquid waste
Ni63		1.00E+00					1.00E+00	1.00E+00	1.00E+00		1.00E-02		
Zn65		1.00E+00					9.80E-02	1.00E+00	1.00E+00		1.00E-02		
Ga67	7.70E+07	8.00E-01	7.50E-01	2.50E-01	1.00E-02	9.90E-01	1.30E-02	1.00E+00	1.00E+00		1.00E-02		accidental loss liquid waste
Se75								1.00E+00	1.00E+00		1.00E-02		
Tc99m	2.10E+10	2.50E-01	7.50E-01	2.50E-01	1.00E-02	9.90E-01	1.00E-03	1.00E+00	1.00E+00		1.00E-02		accidental loss liquid waste
I125	2.80E+07	1.00E+00	7.50E-01	2.50E-01	1.00E-02	9.90E-01	2.40E-01	1.00E+00	1.00E+00		1.00E-02		accidental loss liquid waste
I131	8.00E+07	9.60E-01	7.50E-01	2.50E-01	1.00E-02	9.90E-01	3.30E-02	1.00E+00	1.00E+00		1.00E-02		accidental loss liquid waste
Tl201	5.00E+07	9.00E-01	7.50E-01	2.50E-01	1.00E-02	9.90E-01	1.20E-02	1.00E+00	1.00E+00		1.00E-02		accidental loss liquid waste
Po210		1.00E+00					5.50E-01	1.00E+00	1.00E+00		1.00E-02		
Am241							1.00E+00	1.00E+00	1.00E+00		1.00E-02		

TABLE 6.13

DOSE TO SOLID WASTE WORKERS FROM ACCIDENTAL SPILL

RADIO-ISOTOPE	MASS FLOW TO BE DISPOSED (Bq/a)	CONC. TO GARBAGE WORKER (Bq/cc)	MASS TO SHARU ASH (Bq/a)	MASS DIRECT TO LANDFILL (Bq/a)	CONC. TO SHARU ASH LOADER (Bq/cc)	EXPOSURE CONC. TO LANDFILL WORKER (Bq/cc)	DOSE TO TRUCK DRIVER: DCFt	DOSE TO TRUCK DRIVER: (Sv/a/p)	DCFi	DCFe	DCFg	DOSE FROM GARBAGE (Sv/a/p)	CONC. IN AIR Bq/m3	DOSE FROM EXTERNAL CLOUD INHERS: Iyi (Sv/a/p)	Iye (Sv/a/p)	TOTAL DOSE TO LANDFILL WORKER (Sv/a/p)
H3	2.00E+06	5.56E-07	0.00E+00	5.00E+05	0.00E+00	8.33E-07	0.00E+00	0.00E+00	4.00E-11	0.00E+00	0.00E+00	0.00E+00	1.11E-10	1.07E-17	0.00E+00	1.07E-17
C14	2.50E+06	6.94E-07	0.00E+00	6.25E+05	0.00E+00	1.04E-06	0.00E+00	0.00E+00	5.20E-12	0.00E+00	0.00E+00	0.00E+00	1.39E-10	1.73E-18	0.00E+00	1.73E-18
P32	3.00E+06	8.33E-07	2.23E+06	7.50E+05	8.25E-06	2.78E-07	0.00E+00	0.00E+00	4.40E-09	0.00E+00	0.00E+00	0.00E+00	1.67E-10	1.76E-15	0.00E+00	1.76E-15
P33	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.80E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
S35	1.50E+06	4.17E-07	1.11E+06	3.75E+05	4.13E-06	8.44E-07	0.00E+00	0.00E+00	7.80E-10	0.00E+00	0.00E+00	0.00E+00	8.33E-11	1.56E-16	0.00E+00	1.56E-16
Cr51	3.00E+06	8.33E-07	2.23E+06	7.50E+05	8.25E-06	5.46E-07	1.20E-09	1.50E-12	1.00E-10	4.27E-08	3.70E-09	6.17E-12	1.67E-10	4.00E-17	1.62E-18	6.17E-12
Co57	2.00E+01	5.56E-12	1.49E+01	5.00E+00	5.50E-11	2.80E-11	3.20E-08	2.67E-16	2.90E-09	1.72E-07	1.10E-08	1.22E-16	1.11E-15	7.73E-21	4.36E-23	1.22E-16
Ni63	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.20E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zn65	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-07	0.00E+00	5.70E-09	8.17E-07	7.90E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ga67	6.16E+07	1.71E-05	4.57E+07	1.54E+07	1.69E-04	1.32E-06	4.30E-08	1.10E-09	1.50E-10	1.99E-07	1.70E-08	5.82E-10	3.42E-09	1.23E-15	1.55E-16	5.82E-10
Se75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-07	0.00E+00	2.10E-09	5.30E-07	4.00E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tc99m	5.25E+09	1.46E-03	3.90E+09	1.31E+09	1.44E-02	8.68E-06	3.30E-08	7.22E-08	7.90E-12	1.80E-07	1.20E-08	3.50E-08	2.92E-07	5.53E-15	1.20E-14	3.50E-08
I125	2.80E+07	7.78E-06	2.00E+07	7.00E+06	7.70E-05	1.11E-05	2.70E-11	3.15E-13	9.30E-09	1.50E-08	1.50E-10	2.33E-12	1.56E-09	3.47E-14	5.32E-18	2.37E-12
I131	7.68E+07	2.13E-05	5.70E+07	1.92E+07	2.11E-04	4.19E-06	1.40E-07	4.40E-09	1.10E-08	5.17E-07	5.30E-08	2.26E-09	4.27E-09	1.13E-13	5.03E-16	2.26E-09
Tl201	5.22E+07	1.45E-05	3.88E+07	1.31E+07	1.44E-04	1.04E-06	5.60E-10	1.22E-11	5.90E-11	2.40E-08	1.70E-09	4.93E-11	2.90E-09	4.11E-16	1.59E-17	4.93E-11
Po210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.50E-06	1.19E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Am241	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-09	0.00E+00	1.30E-04	2.57E-08	1.70E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

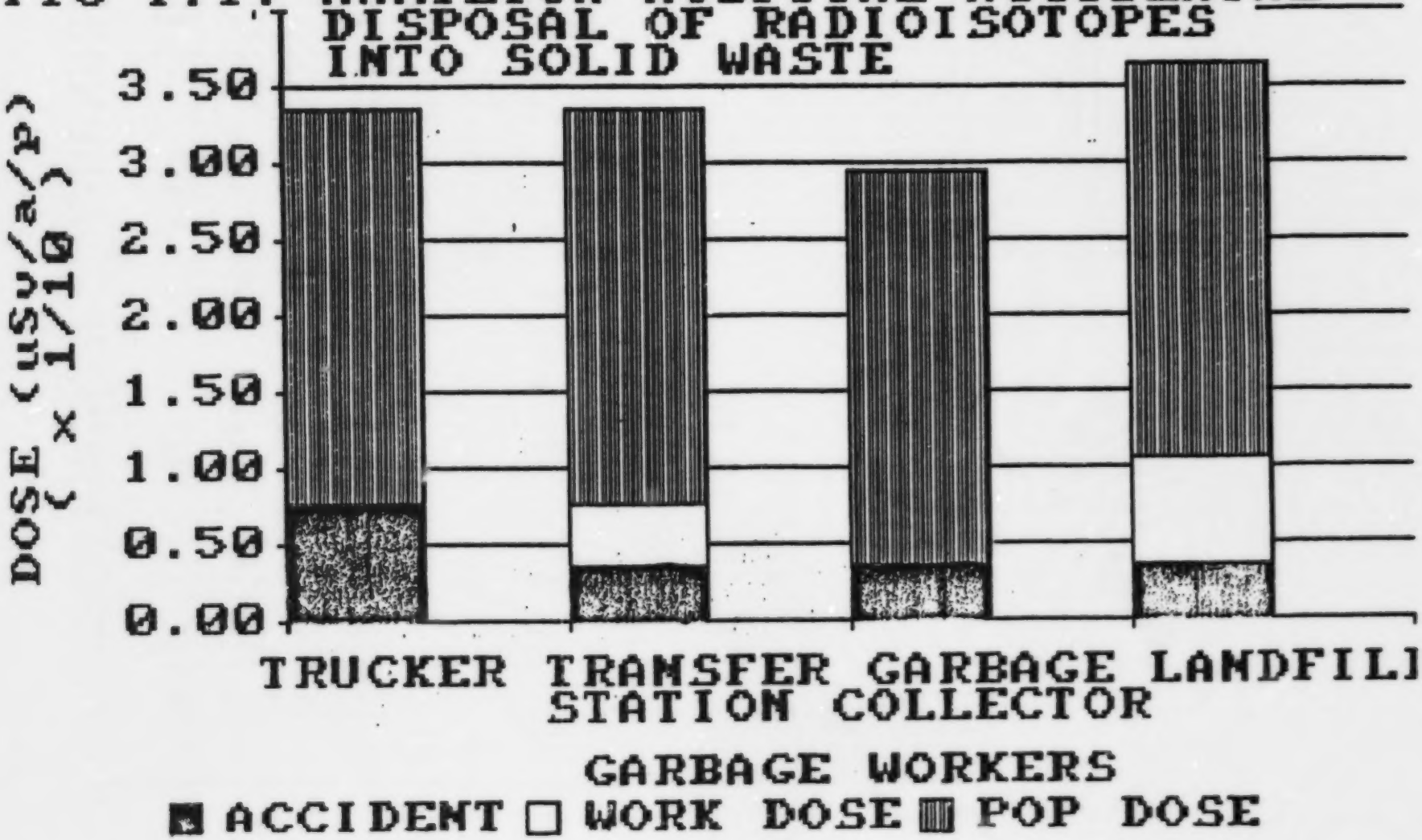
NOTE: COMPUTER - D:TABLE12

TOTAL DOSE 7.78E-08

TOTAL DOSE TO GARBAGE AND TRANS STAT WORKERS 3.79E-08

TOTAL DOSE TO LANDFILL WORKER 3.79E-08

FIG I.1: HAMILTON HOSPITAL ACCIDENTAL DISPOSAL OF RADIOISOTOPES INTO SOLID WASTE



study area (260 uSv/a/p), the total dose to the worker under this scenario would be 369.3 uSv/a/p (Figure I.1). This compares to the regulated maximum dose to members of the general public of 5,000 uSv/a/p.

A second sensitivity analysis was run using waste data provided by AECB as follows:

Radioisotope	Normal (Table G7	AECB Data (Table G7 - Special)
H-3	0	5.60E1
C-14	0	0
P-32	0	0
P-33	0	0
S-35	0	0
Cr-51	0	9.60E1
Co-57	4.00E7	4.00E7
Ni-63	1.00E9	1.00E9
Zn-65	2.00E7	2.00E7
Ga-67	0	1.60E1
Se-75	0	0
Tc-99m	0	1.36E2
I-125	0	3.60E1
I-131	0	3.60E1
Tl-201	0	2.00E8
Po-210	1.00E9	1.00E9
Am-241	6.40E8	6.40E8

The results of this analysis follow in Tables G6, G7, II H9 and H8 (Special Run). These demonstrate the facility of using the model to run different source term loading scenarios. They also demonstrate that the model is sensitive to changes in loading. If one compares Table G7 (Special Run), Column 18 (Exposure Concentrations at Landfill Site) to the same table and column in Appendix G, significant differences will be seen. These differences result from two factors, the change in loading, and the partitioning of all loadings in the second case to the landfill. This latter assumes a city with one landfill and no incinerator unlike the Burlington-Hamilton generic city used in this study.

TABLE 6.6 (SPECIAL RUN)

FACTORS FOR RADIOISOTOPES IN SOLID WASTE

RADIO-ISOTOPE	LOADING TO SOLID WASTE (Bq/s)	DELAY FACTOR IN COLLECTION	DIRECTION OF SOLID WASTE HANDLING: FRAC TO LANDFILL	FRAC TO LANDFILL	SHARU: FRACTION TO AIR	FRACTION TO ASH	DELAY FACTOR IN LANDFILL	FRACTION TO LEACHATE: LANDFILL DIRECT	SHARU AFT. INC.	FRAC TO LEACHATE	FRACTION OF LANDFILL LEACHATE TRANSPORTED: EACH	YEAR	DO (rem/yr)
H3	5.6E+01	1	1				1						
C14		1	1				1						
P32		1	1				0.956						
P33		1	1				0.1						
S35		1	1				0.34						
Cr51	9.6E+01	1	1				0.11						
Co57	4.0E+07	1	1				0.07			1		.	1e6h
Ni63	7.0E+07	1		1			1			1		.	.
Ni65	1.0E+09	1	1		0.01	0.99	1		0.1		1		.
Zn65	2.0E+07	1	1				0.098			1		1	10
Ga67	1.6E+01	0.8	1				0.013						
Se75			1										
Tc99m	1.3E+06	0.25	1				0.001						
I125	3.6E+01	1	1				0.20						
I131	3.6E+01	0.96	1				0.033						
I133	2.0E+00	0.9	1				0.012						
Pu210	1.0E+09	1	1		0.01	0.99	0.55	0.0001	0.1	0.0001	0.01	1	100a
Am241	6.0E+00	1	1		0.01	0.99	1	0.0001	0.1	0.0001	0.0001	1	300r

TABLE 6.7 (SPECIAL RUN)

LOADINGS AND CONCENTRATIONS

RADIO-ISOTOPES	MASS FROM COLLECTED (Bq/s)	LOADING TO LANDFILL (Bq/s)	LOADING TO SHARU (Bq/s)	LOADING DIRECT TO LANDFILL (Bq/s)	CONC. TO GARBAGE HOPPER (Bq/cc)	CONC. INCINER. FEED (Bq/cc)	STACK RELEASE (Bq/s)	MASS TO SHARU ASH (Bq/s)	CONC. OF SHARU ASH (Bq/cc)	MASS TO AFT. INC. ASH (Bq/s)	MASS TO LANDFILL (Bq/s)	LANDFILL CONC (Bq/m2)	EXPOSURE CONC. TO LANDFILL HOPPER (Bq/cc)
H3	5.6E+01	5.6E+01	0.0E+00	5.6E+01	1.5E-11	1.5E-11	5.6E+00	0.0E+00	0.0E+00	0.0E+00	5.6E+01	9.3E-15	9.3E-11
C14	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
P32	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
P33	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
S35	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Cr51	9.6E+01	9.6E+01	0.0E+00	9.6E+01	2.6E-11	2.6E-11	0.0E+00	0.0E+00	0.0E+00	0.0E+00	9.6E+01	1.7E-15	1.7E-11
Co57	4.0E+07	4.0E+07	0.0E+00	4.0E+07	1.1E-05	1.1E-05	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.0E+07	5.0E+01	5.0E-05
Ni63	7.0E+07	7.0E+07	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ni65	1.0E+09	1.0E+09	0.0E+00	1.0E+09	2.7E-04	2.7E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.0E+09	1.6E-03	1.6E-03
Zn65	2.0E+07	2.0E+07	0.0E+00	2.0E+07	5.5E-06	5.5E-06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.0E+07	3.2E-03	3.2E-06
Ga67	1.6E+01	1.2E+01	0.0E+00	1.2E+01	3.5E-12	3.5E-12	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.2E+01	2.7E-17	2.7E-12
Se75	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Tc99m	1.3E+02	3.0E+01	0.0E+00	3.0E+01	9.0E-12	9.0E-12	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.0E+01	5.6E-18	5.6E-14
I125	3.6E+01	3.6E+01	0.0E+00	3.6E+01	1.0E-11	1.0E-11	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.6E+01	1.4E-15	1.4E-11
I131	3.6E+01	3.4E+01	0.0E+00	3.4E+01	9.6E-12	9.6E-12	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.4E+01	1.9E-16	1.9E-12
I133	2.0E+00	1.8E+00	0.0E+00	1.8E+00	5.0E-05	5.0E-05	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.8E+00	3.6E-09	3.6E-06
Pu210	1.0E+09	1.0E+09	0.0E+00	1.0E+09	2.7E-04	2.7E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.0E+09	9.1E-03	9.1E-04
Am241	6.0E+00	6.0E+00	0.0E+00	6.0E+00	1.7E-04	1.7E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	6.0E+00	1.0E-03	1.0E-03

NOTE: COMPUTED 0.7HOUR7.1

TABLE H.6
ANNUAL COMMITTED DOSE (Sv/a) TO:
GARBAGE TRUCK DRIVERS
SPECIAL RUN COMPARED TO
HAMILTON:

RADIOISOTOPE	DCFt	Iga	SPECIAL I9t	HAMILTON I9:
H3	0.00E+00	0.00E+00	0.00E+00	
C14	0.00E+00	0.00E+00	0.00E+00	
P32	0.00E+00	0.00E+00	0.00E+00	
P33	0.00E+00	0.00E+00	0.00E+00	
S35	0.00E+00	2.67E-11	0.00E+00	
Cr51	1.20E-09	1.11E-05	2.00E-11	
Co57	3.20E-08	0.00E+00	0.00E+00	
Ni63	0.00E+00	2.78E-04	0.00E+00	0.00E+00
Zn65	1.90E-07	5.56E-06	1.58E-09	1.58E-09
Ga67	4.30E-08	3.56E-12	2.29E-16	
Se75	2.00E-07	0.00E+00	0.00E+00	
Tc99m	3.30E-08	9.44E-12	4.68E-16	
I125	2.70E-11	1.00E-11	4.05E-19	
I131	1.40E-07	9.60E-12	2.02E-15	
Tl201	5.60E-10	5.00E-05	4.20E-11	
Po210	0.00E+00	2.78E-04	0.00E+00	0.00E+00
Am241	1.80E-09	1.78E-04	4.80E-10	4.80E-10
TOTAL			2.13E-09	2.06E-09

BURLINGTON:

	1	2	3	4	5
1	TABLE H.9				
2	ANNUAL DOSE (Sv/a) TO VARIOUS WORKERS:				
3	GARBAGE COLLECTORS				
4	SPECIAL RUN COMPARED TO				
5	HAMILTON:				
6				SPECIAL	HAMILTON
7	radioisotope	DCFga	Iga	I9ga	I9ga
8					
9	H3	0.00E+00	0.00E+00	0.00E+00	
10	C14	0.00E+00	0.00E+00	0.00E+00	
11	P32	0.00E+00	0.00E+00	0.00E+00	
12	P33	0.00E+00	0.00E+00	0.00E+00	
13	S35	0.00E+00	2.67E-11	0.00E+00	
14	Cr51	1.10E-09	1.11E-05	1.83E-11	
15	Co57	3.00E-08	0.00E+00	0.00E+00	
16	Ni63	0.00E+00	2.78E-04	0.00E+00	0.00E+00
17	Zn65	1.60E-07	5.56E-06	1.33E-09	1.33E-09
18	Ga67	3.80E-08	3.56E-12	2.03E-16	
19	Se75	1.80E-07	0.00E+00	0.00E+00	
20	Tc99m	3.00E-08	9.44E-12	4.25E-16	
21	I125	2.30E-11	1.00E-11	3.45E-19	
22	I131	1.30E-07	9.60E-12	1.87E-15	
23	Tl201	5.00E-10	5.00E-05	3.75E-11	
24	Po210	0.00E+00	2.78E-04	0.00E+00	0.00E+00
25	Am241	1.60E-09	1.78E-04	4.27E-10	4.27E-10
26					
27	TOTAL			1.82E-09	1.76E-09

When one compares the dose calculations, however, there is little difference between the special run and the Hamilton solid waste worker calculations. This results due to the main component of the dose being unchanged and the small dose conversion factors for many of the radioisotopes considered.

TABLE 11 (SPECIAL RUN)

ANNUAL COMMITTED DOSE TO LANDFILL WORKERS

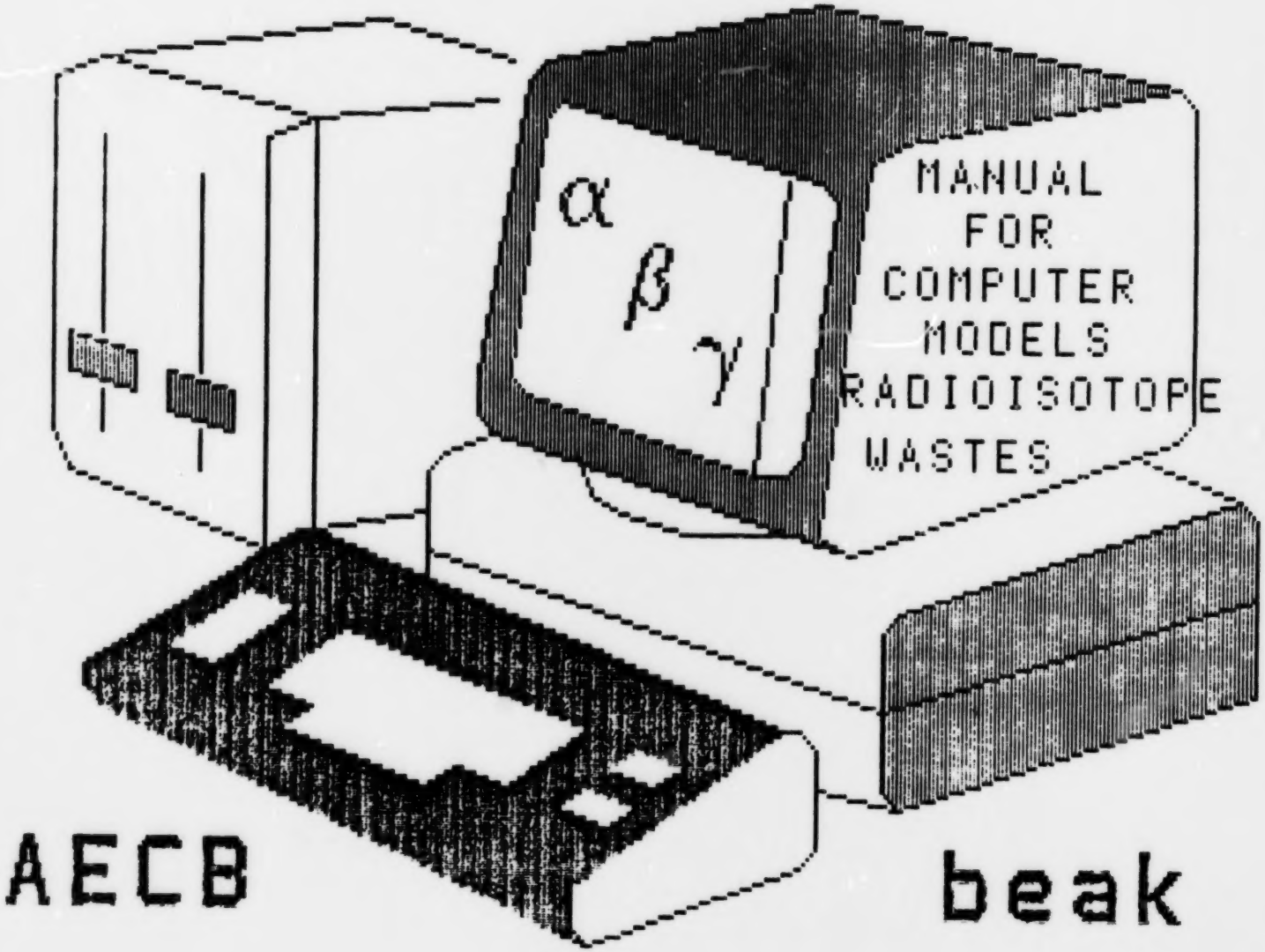
RADIOISOTO	DCFi	DCFe	DCFg	Xi	Xg	Xe	Xe	Xg	XTOTAL
H3	4.00E-11	0.00E+00	0.00E+00	0.00E+00	9.33E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C14	5.20E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
P32	4.40E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
P33	6.80E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
S35	7.80E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cr51	1.00E-10	4.27E-08	3.70E-09	0.00E+00	1.76E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co57	2.90E-09	1.72E-07	1.10E-08	0.00E+00	5.80E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni63	5.20E-10	0.00E+00	0.00E+00	3.30E-07	1.67E-03	4.12E-13	0.00E+00	0.00E+00	4.12E-13
Zn65	5.70E-09	8.17E-07	7.90E-08	0.00E+00	3.27E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ga67	1.50E-10	1.99E-07	1.70E-08	0.00E+00	2.77E-13	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Se75	2.10E-09	5.30E-07	4.00E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tc99m	7.90E-12	1.80E-07	1.20E-08	0.00E+00	5.67E-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I125	9.30E-09	1.50E-08	1.50E-10	0.00E+00	1.44E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I131	1.10E-08	5.17E-07	5.30E-08	0.00E+00	1.90E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl201	5.90E-11	2.40E-08	1.70E-09	0.00E+00	3.60E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po210	2.50E-06	1.19E-11	0.00E+00	1.46E-07	9.17E-04	8.73E-10	3.95E-19	0.00E+00	8.73E-10
Am241	1.30E-04	2.57E-08	1.70E-09	1.67E-07	1.07E-03	5.22E-08	9.81E-16	2.84E-09	5.51E-08

TOTAL: 5.59E-08

APPENDIX J

User's Manual

This is provided in a separate volume to facilitate use.


α
β
γ
MANUAL
FOR
COMPUTER
MODELS
RADIOISOTOPE
WASTES
AECB
beak

INTRODUCTION

The computer model used in this study is activated through a series of interrelating mathematical spreadsheets in which calculations are made on a column-by-column basis. The tables which follow indicate the relationships between the spreadsheets. The spreadsheets are presented in Appendices G and H of the project report.

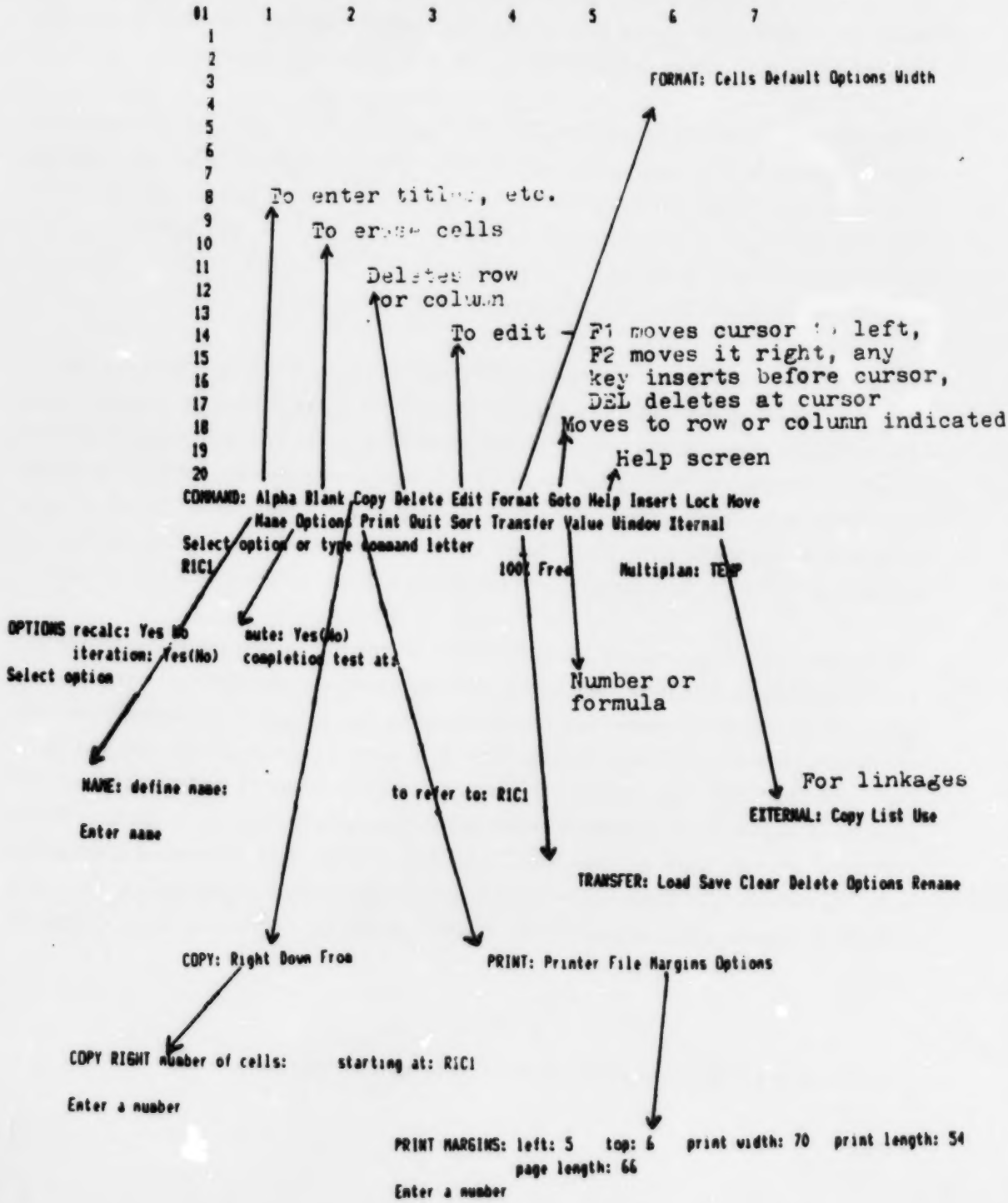
A commercial software package MULTIPLAN* was used in this study. It is copyright by Microsoft. The original spreadsheet entries were made using a Nabu 1600 microcomputer with Xenix disc operating system (DOS) by Microsoft. To facilitate use by AECB, the data files were transferred to an IBM-PC disc. Further revisions and quality assurance checks were run on a SANYO-775 microcomputer with Microsoft 2.11 DOS and Multiplan 1.06 program (for COMPAQ microcomputer).

Multiplan is a menu-driven spreadsheet program. This means that operations can be controlled by using keys which correspond to the first letter of operation names which appear on the "menu" at the bottom of the screen (Figure 1). The main menu screen can always be accessed by pushing the control and C keys simultaneously. Many of the main menu keys access sub-menues. For example, pushing T for Transfer on the main menu gives you a sub-menu with Load, Save, Clear, Delete, Options and Rename actions (Figure 1.). Pushing L for Load will then result in a prompt for which data file to load.

For the function of this "model", it is necessary to link the various tables or spreadsheet files. This means that later tables (the dose calculations in Appendix H) have columns which are dependent on preceeding tables (Appendix G). In such cases, changes can only be made on the original table and all those depending on it will change automatically. For example, Table G7, Column 18 presents concentrations of radioisotopes in the Hamilton Landfill. This column is required for calculations of doses to Garbage Truck Drivers (Table H8), Garbage Collectors (Table H9), Transfer Station Workers (Tables H10, H15), and Landfill Site Workers (Table H11). By linking it, any changes made in Table G7, Column 18 automatically appear in all of the appropriate columns in these dependent tables.

* Multiplan is a licensed software program, copyright by Microsoft.

FIGURE 1: MULTIPLAN MAIN SCREEN AND COMMAND ACTIONS OR INTERCONNECTIONS WITH SUB-MENU SCREENS



Multiplan is a powerful program with many possible mathematical operations. Those who wish to learn more about it are referred to a number of available Multiplan guidebooks:

- Microsoft Corporation. 1982. Microsoft (tm) Multiplan (tm) Manual
- R.E. Williams. 1982. The Power of Multiplan
- A. Simpson, 1984. The Best Book of Multiplan. Sams, Indianapolis (this is the reference used in the current study).

Table I is a list of the titles of spreadsheets along with their Multiplan file codes. These codes are used to access the various spreadsheets with the Multiplan disk in A drive and data disk in B drive.

Note:

The Multiplan program presents the linkage or formula for each cell when the cursor is on that cell. This is presented at the lower left of the screen. Examples:

- **RC [-3] x RC [-1]**: This means the number in the cell in which the cursor exists (for example, Row 3, Column 6 or R3C6) is calculated by multiplying the cell in the same row three columns to left by the cell in the same row one column to left (for example, R3C3 x R3C5).

- **b:table7.1 csa:** This column is taken by linkage from Table G7, Column 12 (concentration SWARU ash).

- **R [-26] C [+1]**: This number is taken from a cell 26 rows up and one column to right. This occurs when two or more tables are on the same spreadsheet.

TABLE 1: SPREADSHEET TABLES (APPENDIX G AND H) WITH COMPUTER FILE CODES

Table		Computer Code
G.1	Hamilton WWTP Partition Factors	B:TABLE2
G.2	Hamilton WWTP Calculations	B:TABLE2
G.5	Surface Water Factors	B:TABLE5
G.6	Factors for Radioisotopes in Solid Waste	B:TABLE7.1
G.7	Loadings and Concentrations	B:TABLE7.1
G.8	Calculating Seepage Mass Flow from Hamilton Landfill to Hamilton Harbour (via Red Hill Creek)	B:TABLE7.1
G.9	Calculating Seepage Mass Flow from Burlington Landfill to Burlington WWTP	B:TABLE7.1
G.10A	Burlington WWTP Partition Factors	B:TABLE10
G.10B	Burlington WWTP Calculations	B:TABLE10
G.11	Surface Water	B:AECBHAM5 (rows 1-27)
G.12	Factors for Radioisotopes Accidentally Disposed to Solid Waste	B:TABLE12
G.13	Calculating Dose to Solid Waste Workers due to Accidental Disposal of Radioisotopes	B:TABLE12
H.1	Collective Dose from Atmospheric Releases	B:AECBHAM4
H.2	Dose from Atmospheric Releases--Critical Group in General Population	B:AECBHAM3
H.3	Dose from Aquatic Releases--Collective and Critical Group in General Population	B:AECBHAM5 (rows 29-57)
H.4	Annual Committed Dose to Sludge Worker	B:ACDSW
H.5	Annual Committed Dose Aeration Worker--STP	B:ACDAW
H.6	Annual Committed Dose to Ash Loader--STP	B:ACDALSTP

TABLE 1: SPREADSHEET TABLES (APPENDIX G AND H) WITH COMPUTER FILE CODES (cont'd)

Table		Computer Code
H.7	Annual Committed Dose to Truck Driver--STP	B:ACDTDSTP
H.8	Annual Committed Dose to Garbage Truck Drivers	B:H8
H.9	Annual Committed Dose to Garbage Collectors	B:H9
H.10	Annual Committed Dose: Truck Driver-Hamilton	B:H10
H.11	Annual Committed Dose to Landfill Site Workers	B:H11
H.12	Annual Committed Dose to Loader--SWARU	B:H12
H.13	Annual Committed Dose to Truck Driver--SWARU	B:H13
H.14	Annual Committed Dose to Sorter--SWARU	B:H14
H.15	Annual Committed Dose to Loaders at Transfer Stations in Hamilton	B:H15

TABLE G1: HAMILTON SEWAGE TREATMENT PLANT PARTITIONING
(Disk B:TABLE2, Rows 1-23)

Column 1: radioisotopes studied.

Column 2: is the annual loading (Bq/a) of radioisotopes to the Hamilton sewer system from all sources (Report Table 4.2).

Column 3: is the fraction of the loading of radioisotopes in the sewer lost in the sewer due to radioactive decay during transit to the WWTP (Report Table 4.2).

Column 4: is the fraction of the loading to the WWTP lost to the atmosphere due to aeration (Report Table 4.2).

Column 5: is the fraction of the radioisotope loading to the WWTP that is partitioned to the aeration tank sludge (Report Table 4.2).

Column 6: is the fraction of radioisotope loading to the WWTP lost in the WWTP due to radioactive decay.

Column 7: is the fraction of radioisotope loading to the WWTP discharge to surface water in the effluent.

Column 8: is the fraction of radioisotope partitioned to sludge (Column 5) lost to radioactive decay in the mixed liquor of the aeration tank.

Column 9: is the fraction of radioisotope in sludge (Column 5) that is partitioned to the digester.

Column 10: is the fraction of radioisotope in the digester that is lost to the digested gas by anaerobic metabolism and then released to the atmosphere by burning digester gas (carbon-14 and tritium).

Column 11: is the fraction of radioisotope entering the digester lost in the digester due to radioactive decay.

Column 12: is the fraction of radioisotope entering the digester which is partitioned to the sludge incinerator.

Column 13: is the fraction of radioisotope loading to the incinerator that is partitioned to the atmosphere as a gas (carbon-14 and tritium) or as fly ash released from the stack.

Column 14: is the fraction of radioisotope entering the incinerator which accumulates in ash on a weekly basis before its disposal.

TABLE G2: HAMILTON WASTEWATER TREATMENT PLANT CALCULATIONS
(Disk B:TABLE2, Rows 26-52)

Column 1: is the list of radioisotopes studied.

Column 2: is the annual loading (Bq/a) of radioisotopes to the WWTP from all sources (Table G1, Column 2 (Column 2 x Column 3)).

Column 3: is the annual release (Bq/a) from the WWTP to surface water (Column 2 x Table G1, Column 7).

Column 4: is the annual release (Bq/s) from the WWTP to surface water (Column 3/3.16E7 s/a).

Column 5: is the annual amount of radioisotope (Bq/a) partitioned to sludge at the WWTP (Column 2 x Table G1, Column 5).

Column 6: is the annual amount of radioisotope (Bq/a) from sludge partitioned to the digester (Column 5 x Table G1, Column 9).

Column 7: is the annual amount of radioisotope (Bq/a) from the digester partitioned to the incinerator (Column 6 x Table G1, Column 12).

Column 8: is the amount of radioisotope (Bq/a) entering the WWTP incinerator which accumulates in the ash fraction in a week before disposal (Column 7 x Table G1, Column 14).

Column 9: is the rate of release of radioisotope (Bq/s) from the aeration tank to the atmosphere due to volatilization (Column 2 x Table G1, Column 4/3.16E7 s/a).

Column 10: is the rate of release of radioisotope (Bq/s) from the digester to the digester gas due to anaerobic metabolism (Column 7 x Table G1, Column 10/3.16E7 s/a).

Column 11: is the annual release of radioisotope (Bq/s) from the incinerator stack in the form of gas (for tritium and carbon-14) (Column 5 x Table G1, Column 12 x Table G1, Column 13/3.15E7 s/a), or as particulate fly ash (for other radioisotopes) (Column 8 x Table G1, Column 13/3.16E7 s/a).

Column 12: is the concentration of radioisotope in the aeration tanks (Bq/cc) (Column 3 + Column 6/1.12E14 cc/a).

Column 13: is the concentration of radioisotope in the sludge filters (Bq/cm^3) (Column 7/7.2E10 cc/a).

Column 14: is the concentration of radioisotope in dry ash (Bq/cm^3) (Column 8/1.2E10 cc/a).

Column 15: stack release (Bq/s) (Column 10 + Column 11).

TABLES G3 and G4 are replaced by Table G10

TABLE G5: SURFACE WATER FACTORS
(Disk B:TABLE5)

Column 1: is the list of radioisotopes studied.

Column 2: are radioactive half-lives in days (d) or years (y).

Column 3: are radioactive decay rates in $days^{-1}$ or $years^{-1}$ (1/Column 2).

Column 4: are fractions of radioisotope decay while in WWTP ash pit.

Column 5: dilution factor as water passes through Hamilton Harbour to Lake Ontario (Table 10.1 in Report).

Column 6: is the dilution factor in Lake Ontario before radioisotopes reach the Drinking Water inlet.

TABLE G6: SOLID WASTE FACTORS FOR RADIOISOTOPES IN SOLID WASTE (Disk B:TABLE7.1, Rows 1-26)

Column 1:	radioisotopes considered.
Column 2:	is the annual loading of radioisotopes (Bq/a) to the Hamilton-Burlington solid waste disposal system (Report Table 4.1).
Column 3:	is the fraction of the annual loading (Column 2) lost in solid waste disposal (due to decay).
Columns 4-7:	indicate fractions of radioisotopes handled by various solid waste disposal pathways (incineration, landfill sites, apartment incinerators) (Report Table 4.1).
Column 10:	is the fraction of the annual radioisotope loadings to the landfills remaining after radioactive decay.
Column 11:	is the fraction of radioisotope annually leached to soil moisture and the sorbed phase from unincinerated solid waste in the landfill at Hamilton.
Column 12:	is the fraction of radioisotope annually leached to soil moisture and the sorbed phase from incinerator ash in the landfill at Hamilton.
Column 13:	is the fraction of radioisotope annually leached from unincinerated solid waste to soil moisture and the sorbed phase in the landfill at Burlington.
Columns 14, 15:	are the fractions of leachate generated at Hamilton and Burlington landfills entering Red Hill Creek or the Burlington WWTP collection system annually.
Column 16:	adsorption coefficient (Kd) in Hamilton landfill (cc/g).
Column 17:	is the source of radioisotope in the waste.

TABLE G7: LOADINGS AND CONCENTRATIONS FROM SOLID WASTE DISPOSAL (Disk B:TABLE7.1, Rows 28-56)

Column 1: is the list of radioisotopes studied.

Column 2: is the annual radioisotope loading to the solid waste of Hamilton-Burlington (Bq/a) (Table G6, Column 1).

Column 3: is the total annual loading for disposal after accounting for decay in the collection system (Column 2 x Table G6, Column 3).

Column 4: is the annual loading (Bq/a) to the municipal incinerator (Column 3 x Table G6, Column 4).

Column 5: is the annual loading of solid waste (Bq/a) disposed directly to the landfill in Hamilton (Column 3 x Table G6, Column 5) without incineration.

Column 6: is the annual loading of solid waste disposed directly (Bq/a) to the landfill in Burlington (Column 3 x Table G6, Column 6) without incineration.

Column 7: is the radioisotope activity in solid waste in Hamilton collection system (Bq/cm^3) (Column 4 + Column 5)/3.6E6 m^3/a/1E6 cc/m^3).

Column 8: is the radioisotope activity in solid waste in Burlington collection system (Bq/cm^3) (Column 3 x Table G6, Column 6/7.2E5 m^3/a/1E6 cc/m^3).

Column 9: is the radioisotope activity in solid waste entering the municipal incinerator (Bq/cm^3) (Column 7).

Column 10: is the rate of radioisotope release from the municipal incinerator (Bq/s) (Column 4 x Table G6, Column 8/3.16E7 s/a).

Column 11: is the annual release of radioisotope (Bq/a) with incinerator ash (Column 4 x Table G6, Column 9).

Column 12: is the activity of radioisotope in municipal incinerator ash (Bq/cm^3) (Column 11/2.7E5 m^3/a/1E6 cc/m^3).

Column 13: is the annual release of radioisotope (Bq/a) with apartment incinerator ash (Column 2 x Table G6, Column 3 x Table G6, Column 7).

Column 14: is the annual amount of radioisotope (Bq/a) disposed to the Hamilton landfill (Column 5 + Column 11 + Column 13).

Column 15: is the annual amount of radioisotope (Bq/a) disposed to the Burlington landfill (Column 6).

Column 16: is the concentration of radioisotope (Bq/m^3) in the Hamilton landfill, accounting for dilution by soil and radioactive decay (Column 14 x Table G6, Column 10/6E5 m^3/a).

TABLE G7: LOADINGS AND CONCENTRATIONS FROM SOLID WASTE DISPOSAL (Disk B:TABLE7.1, Rows 28-56)

Column 17: is the concentration of radioisotope (Bq/m^3) in the Burlington landfill, accounting for dilution by soil and radioactive decay (Column 15 x Table G6, Column 10/1.8E5 m^3/a).

Column 18: is the concentration of radioisotope (Bq/cm^3) in the Hamilton landfill (Column $16/10^6$ cm^3/m^3).

Column 19: is the concentration of radioisotope (Bq/cm^3) in the Burlington landfill (Column $17/10^6$ cm^3/m^3).

TABLE G8: SEEPAGE MASS FLOW FROM HAMILTON LANDFILL TO HAMILTON HARBOUR (Disk B:TABLE7.1)

Column 1: is the list of radioisotopes studied.

Column 2: is potential leachate from Hamilton garbage disposed directly to the landfill (i.e., non-incinerated) (Table G6, Column 11 x Table G7, Column 5) (Bq/a).

Column 3: is potential leachate from SWARU incinerator ash disposed to the Hamilton landfill ((Table G7, Column 3 + Table G7, Column 4) x Table G6, Column 12 (Bq/a).

Column 4: is total potential concentration of leachate in the landfill (Column 2 + Column 3) x Table G6, Column 10/6E5 m^3/a (Bq/m^3).

Column 5: is actual landfill leachate, after accounting for adsorption Column 4/(1 + (1.5 (Table G6, Column 16)/0.4 gm/cc)).

Column 6: is mass flow to Hamilton Harbour from Red Hill Creek from Hamilton landfill (Bq/a) Column 5 x Table G6, Column 14 x 2.5E4 m^3/a.

TABLE G9: SEEPAGE MASS FLOW FROM BURLINGTON LANDFILL TO BURLINGTON WWTP (Disk B:TABLE7.1)

Column 1: is the list of radioisotopes studied.

Column 2: mass flow to Burlington landfill (Bq/a) from the Burlington solid waste collection system ((Table G10B, Column 12) + (Table G6, Column 2 x Table G6, Column 6)).

Column 3: total concentration in the Burlington landfill (Bq/m^3) (Column 2 x Table G6, Column 10)/1.8E5 m^3/a).

Column 4: potential concentration of leachate in Burlington landfill after accounting for portion of radionuclide in non-leachable, geological materials (Bq/m^3) (Column 3 * Table G6, Column 13).

Column 5: actual concentration of leachate from Burlington landfill after accounting for adsorption (Bq/m^3) (Column 3/(1 + (1.5 x Table G6, Column 6)/0.4)).

Column 6: mass flow from Burlington landfill to Burlington Wastewater Plant (Bq/a) (Column 5 x Table G6, Column 15 * 2.5E4 m^3/a).

Column 7: direct exposure concentration of landfill workers (Bq/cc) (Column 3/1E6 cc/m^3).

Column 8: exposure concentration of landfill workers from dust at landfill site (Bq/cc) (Column 4/1E6 cc/m^3).

Column 9: spaces

Column 10: spaces

Column 11: loading to Burlington landfill from Burlington Wastewater Treatment Plant (Bq/a) (Table G10B, Column 12).

TABLE G10A: PARTITIONING FACTORS FOR THE BURLINGTON WASTEWATER TREATMENT PLANT (Disk B:TABLE10, Rows 1-25)

Column 1: is the list of radioisotopes studied.

Column 2: mass flow of leachates with Burlington landfill seepage collected by underdrain system (Bq/a) (Table G9, Column 6).

Column 3: loading to Burlington sewer system from industry, institutions and homes.

Column 4: loss of radionuclides in sewer due to decay, adsorption, etc.

Column 5: Wastewater Treatment Plant fraction partitioned to atmosphere in aeration tank.

Column 6: Wastewater Treatment Plant fraction partitioned to sludge.

Column 7: loss in liquid sewage due to decay while in treatment plant.

Column 8: Wastewater Treatment Plant fraction partitioned via effluent into Hamilton Harbour.

Column 9: fraction of radionuclide partitioned to activated sludge loss to decay in sludge.

Column 10: fraction of radionuclide in activated sludge to its effluent (i.e., influent to digester).

Column 11: fraction of radionuclide in digester partitioned to digester gas.

Column 12: fraction of radionuclide in digester loss to decay in digester.

Column 13: fraction of radionuclide entering digester partitioned to landfill in digester sludge.

TABLE G10B: SEWER AND LANDFILL LOADINGS FROM BURLINGTON WASTEWATER TREATMENT PLANT (Disk B:TABLE10, Rows 28-53)

Column 1: lists the radioisotopes studied.

Column 2: total loading to Wastewater Treatment Plant (Bq/a) (Table G10A, Column 2 + ((Table G10A, Column 3) x (1 - Table G10A, Column 4))).

Column 3: mass flow in Burlington WWTP effluent to Hamilton Harbour (Bq/a) (Column 2 x Table G10A, Column 8).

Column 4: mass flow in Burlington WWTP effluent (Bq/s) (Column 3 x 3.16E7 s/a).

Column 5: mass flow in sludge in aeration tank of Burlington WWTP (Bq/a) (Column 2 x Table G10A, Column 6).

Column 6: mass flow of radionuclides in sludge entering digester at Burlington WWTP (Bq/a) (Column 5 x Table G10A, Column 10).

Column 7: mass flow to air from aeration tank at Burlington WWTP (Bq/a) (Column 2 x Table G10A, Column 5).

Column 8: mass flow to digester gases in Burlington WWTP (Bq/a) (Column 6 x Table G10A, Column 11).

Column 9: exposure concentration of aerator worker at Burlington WWTP (Bq/cc) ((Column 3 + Column 5)/1.12E14 cc/yr).

Column 10: concentration in sludge disposed from Burlington WWTP (Bq/cc) (Column 12/7.2E10 cc/yr).

Column 11: release to atmosphere from digester gases at Burlington WWTP (Bq/s) (Column 8/3.16E7 s/a).

Column 12: loading to Burlington landfill from Wastewater Treatment Plant sludge (Bq/a) (Column 6 x Table G10A, Column 13).

TABLE G11: SURFACE WATER
(Disk B:AECBHAM5, Rows 1-27)

Column 1: lists radioisotopes studied.

Column 2: is the release (Bq/a) of radioisotopes in effluent from the Hamilton WWTP (Table G2, Column 3).

Column 3: is the release (Bq/a) of radioisotopes in effluent from the Burlington WWTP (Table G10B, Column 3).

Column 4: is the annual release (Bq/a) of radioisotopes from the Hamilton landfill to Hamilton Harbour (Table G8, Column 6).

Column 5: is the annual release (Bq/a) of radioisotopes to Hamilton Harbour from all sources (Column 2 + Column 3 + Column 4).

Column 6: is the dilution-reaction factor of radioisotope on passage through Hamilton Harbour to Lake Ontario (Table G5, Column 5).

Column 7: is the annual release (Bq/a) of radioisotopes entering Lake Ontario from Hamilton Harbour (Column 5 x Column 6).

Column 8: is the average concentration (Bq/m^3) of radioisotope in Hamilton Harbour (Column 7/2.2E9 m^3/a).

Column 9: is the dilution-reaction factor between Hamilton Harbour outlet and the intake for the WTP (Table G5, Column 6).

Column 10: is the concentration of radioisotope (Bq/m^3) at the municipal water intake in Lake Ontario (Column 8 x Column 9).

Column 11: is the fraction of radioisotope removed by water treatment in the water treatment plant.

Column 12: is the concentration of radioisotope (Bq/L) in municipal drinking water (Column 10 x Column 11/1,000 L/m^3).

TABLE G12: FACTORS FOR LIQUID RADIOISOTOPES ACCIDENTLY DISPOSED TO HAMILTON SOLID WASTE (Sensitivity Analysis of Table G6 with Number of Additional Waste Loadings to Simulate Accidental Hospital Disposal of Radioisotopes into Garbage) (Disk B:TABLEI2, Rows 1-25)

Column 1:	lists the radioisotopes studied.
Column 2:	annual loading due to accidental disposal (Bq/a).
Column 3:	fraction to account for decay during collection (Table G6, Column 3).
Column 4:	fraction of waste partitioned to SWARU.
Column 5:	fraction of waste partitioned to Hamilton landfill (1.0 minus Column 4).
Column 6, 7:	spaces (for Burlington. Not needed because this table considers Hamilton only).
Column 8:	fraction of solid was to entering SWARU partitioned to air pathways at SWARU.
Column 9:	fraction partitioned to ash at SWARU (1.0 minus Column 8).
Column 10:	factor to account for radioisotope decay in Hamilton landfill (same as Table G6, Column 10).
Column 11:	fraction of garbage disposed directly to Hamilton landfill available for leaching.
Column 12:	fraction of incinerator ash at Hamilton landfill available for leaching.
Column 13:	space (relevant only for Burlington).
Column 14:	fraction of Hamilton landfill leachate draining to Red Hill Creek annually.
Column 15:	space (relevant only for Burlington).
Column 16:	description of source of accidental release.

TABLE G13: DOSE TO SOLID WASTE WORKERS DUE TO ACCIDENTAL DISPOSAL OF LIQUID RADIOISOTOPES (as per Table G12) (Disk B:TABLE12, Rows 28-55)

Column 1: lists radioisotopes studied.

Column 2: mass flow disposed to Hamilton garbage (Table G12, Column 2 x Table G12, Column 3) (Bq/a).

Column 3: concentration affecting garbage collectors (Bq/cc) (Column 2/3.6E6 m^3/a/1E6 cc/m^3).

Column 4: mass flow disposed in SWARU ash (Bq/a) (Column 2 x Table G12, Column 4 x Table G12, Column 9).

Column 5: mass flow disposed directly to Hamilton landfill (Bq/a) (Column 2 x Table G12, Column 5).

Column 6: concentration affecting SWARU ash loader (Bq/cc) (Column 4/2.7E5 m^3/a/1E6 cc/m^3).

Column 7: concentration affecting Hamilton landfill site worker (Bq/cc) ((Column 4 + Column 5)/(6E5 m^3/a/1E6 cc/m^3) x Table G12, Column 10).

Column 8: dose conversion factor for gamma radiation ((Sv/h)/(Bq/cc)) (Table H8, Column 2).

Column 9: dose to garbage truck driver (Sv/a/p) (Column 3 x Column 8 x 1.5E3 h/a).

Column 10: dose conversion factor for inhalation (Table H11, Column 2 (Sv/Bq).

Column 11: dose conversion factor for external cloud immersion (Table H11, Column 3) ((Sv/a)/(Bq/m^3)) (Appendix B, Table B3 in Report).

Column 12: dose conversion for gamma from garbage ((Sv/h)/(Bq/cc)) (Table H11, Column 4).

Column 13: dose from garbage (Sv/a/p) (Column 12 x Column 3 x 2,000 h/a).

Column 14: concentration in air (Bq/m^3) (Column 3 x ((2E-4 g/m^3)/(1 g/cc)).

Column 15: dose from inhalation (Sv/a/p) (Column 10 x Column 14 x 2,000 h/a x 1.2 m^3/h breathed).

Column 16: dose from external cloud immersion (Column 11 x Column 14 x 2,000 h/a worked/8,760 h/a).

Column 17: total dose to landfill worker (Sv/a/p) (Column 16 + Column 15 + Column 13).

TABLE H1: POPULATION DOSE FROM ATMOSPHERIC RELEASES
(Disk B:AECBHAM4)

This spreadsheet computes collective dose for the general population of Hamilton-Burlington through atmospheric pathways.

Column 1: lists radioisotopes studied.

Column 2: indicates the waste streams (radioisotope sources), as foot-noted.

Column 3: is the annual release (Bq/s) from 2A: the WWTP digester and incinerator (Table G2, Column 15 + 2B: aeration tanks (Table G2, Column 9 + Table G10, Column 7) and from 3: the municipal incinerator (Table G7, Column 10).

Column 4: lists the atmospheric dilution factors applied to stack releases (4.60E-8) and ground level (aeration tank) releases (5.5E-7), based on average population per sector and average distance of each sector from the source. These are site-specific values.

Column 5: is the average radioisotope activity (Bq/m^3) in air at ground level (Column 3 x Column 4).

Column 6: is the air to ground transfer parameter (m) for calculating radioisotope activities in vegetated soil. Default values from Table A1, Appendix 1 of the main report are applied.

Column 7: is the radioisotope activity in vegetated soil (Bq/m^2) (Column 5 x Column 6).

Column 8: lists the committed effective dose equivalent conversion factors (Sv/Bq) for inhalation of airborne radioisotopes $(DCF)_i$.

Column 9: is the transfer parameter relating $(DCF)_i$ to dose (units $Sv \cdot a^{-1} \cdot Bq^{-1} \cdot m^3$) based on standard breathing volume of 8.4E3 m^3/a (Column 8 x 8.4E3 m^3/a).

Column 10: lists the dose equivalent conversion factors ($Sv \cdot a^{-1} \cdot Bq^{-1} \cdot m^3$) for immersion in a cloud of radioactive material $(DCF)_e$.

Column 11: is the transfer parameter relating $(DCF)_e$ to dose ($Sv \cdot a^{-1} \cdot Bq^{-1} \cdot m^3$) based on the relationship $P(e)_{19} = (f_u + (1-f_u)\,S)\,(DCF)_e\ Sv \cdot a^{-1} \cdot Bq^{-1} \cdot m^3$ where f_u is the fraction of time an individual spends outdoors, assumed to be 0.2, and S is the shielding factor afforded by buildings, assumed to be 0.75. Thus, Column 11 = 0.8 x Column 10.

TABLE H1: POPULATION DOSE FROM ATMOSPHERIC RELEASES
(Disk B:AECBHAM4)

Column 12: lists the dose equivalent conversion factors ($Sv \cdot a^{-1} \cdot Bq^{-1} \cdot m^2$) for exposure above a uniformly contaminated plane $(DCF)_g$.

Column 13: is the transfer parameter relating $(DCF)_g$ to dose ($Sv \cdot a^{-1} \cdot Bq^{-1} \cdot m^2$), based on the relationship $P_{39} = 0.364 \times (DCF)_g$, or 0.364 x Column 12, where 0.364 is a factor that accounts for out-of-doors exposure time, non-uniformity of the ground surface and exposure while indoors with shielding from buildings.

Column 14: is the average per capita dose from atmospheric releases (Column 9 + (Column 5 x Column 11) + (Column 7 x Column 13) (Sv/a/p).

Column 15: is the collective dose from atmospheric releases summed over the Hamilton-Burlington population of 525,000 (Column 14 x 525,000) (Sv/a).

Column 16: space

Column 17: space

Column 18: digester release to air (Table G10B, Column 11) (Bq/s).

Column 19: stack release (Table G7, Column 10).

Column 20: loss to air from aeration tanks (Table G10B, Column 7) (Bq/a).

Column 21: stack release (Table G2, Column 15).

Column 22: loss to air from aerator (Table G2, Column 9).

TABLE H2: DOSE FROM ATMOSPHERIC RELEASES - POPULATION CRITICAL GROUP (Disk B:AECBHAM3)

This spreadsheet computes annual doses through atmospheric pathways to individuals living in the critical group within the general Hamilton-Burlington population. The critical group is assumed to be exposed to the maximum average atmospheric concentrations of radioisotopes from stack releases at the municipal solid waste incinerator and the wastewater treatment plant incinerator.

Column 1: lists the radioisotopes studied.

Column 2: indicates the waste streams (radioisotope sources), as foot-noted.

Column 3: is the annual release (Bq/s) from 2A: the WWTP incinerator and digestor (Table G1, Column 10 + Table G1, Column 15 + Table G4, Column 11), 2B: aeration tanks (Table G1, Column 9 + Table G4, Column 11) and from 3: the municipal incinerator (Table G7, Column 10) (= Table H1, Column 3).

Column 4: lists the atmospheric dilution factors applied to atmospheric releases for a critical group located in the area where average dilution is minimal for a stack height of 50 m. This value is taken to be 1.10E-6 s/m^3, which is three times the highest dilution factor for average meteorological conditions. The critical group in this case is located about 500 m from the source location. For ground level releases, three times the highest dilution factor is 1.2E-5 s/m^3. These values may be adjusted to suit any particular set of meteorological conditions and critical group locations.

Column 5: is the average concentration of radioisotope in air at ground level (Bq/m^3) (Column 3 x Column 4).

Column 6: is the air to ground transfer parameter (m) for calculating radioisotope activities in vegetated soil. Default values from Table A1, Appendix 1 of the main report are applied.

Column 7: is the radioisotope activity in vegetated soil (Bq/m^2) (Column 5 x Column 6).

Column 8: lists the committed effective dose equivalent conversion factors (Sv/Bq) for inhalation of airborne radioisotopes $(DCF)_i$ by adults.

Column 9: is the transfer parameter relating $(DCF)_i$ to dose (units $Sv \cdot a^{-1} \cdot Bq^{-1} \cdot m^3$) based on standard breathing volume of 8.4E3 m^3/a by adults (Column 8 x 8.4E3 m^3/a).

Column 10: lists the committed effective dose equivalent conversion factors (Sv/Bq) for inhalation of airborne radioisotopes $(DCF)_i$ by infants.

TABLE H2: DOSE FROM ATMOSPHERIC RELEASES - POPULATION CRITICAL GROUP (Disk B:AECBHAM3)

Column 11: is the transfer parameter relating $(DCF)_i$ to dose (units $Sv \cdot a^{-1} \cdot Bq^{-1} \cdot m^3$) based on standard breathing volume of 1.4E3 m^3/a by infants (Column 10 x 1.4E3 m^3/a).

Column 12: lists the dose equivalent conversion factors ($Sv \cdot a^{-1} \cdot Bq^{-1} \cdot m^3$) for external immersion in a cloud of radioactive material $(DCF)_e$.

Column 13: is the transfer parameter relating $(DCF)_e$ to dose ($Sv \cdot a^{-1} \cdot Bq^{-1} \cdot m^3$) based on the relationship $P(e)_{19} = (f_u + (1-f_u)\ S)\ (DCF)_e\ Sv \cdot a^{-1} \cdot Bq^{-1} \cdot m^3$ where f_u is the fraction of time an individual spends outdoors, assumed to be 0.2, and S is the shielding factor afforded by buildings, assumed to be 0.75. Thus, Column 11 = 0.8 x Column 10.

Column 14: lists the dose equivalent conversion factors ($Sv \cdot a^{-1} \cdot Bq^{-1} \cdot m^2$) for exposure above a uniformly contaminated plane $(DCF)_g$.

Column 15: is the transfer parameter relating $(DCF)_g$ to dose ($Sv \cdot a^{-1} \cdot Bq^{-1} \cdot m^2$), based on the relationship $P_{39} = 0.364 \times (DCF)_g$, or 0.364 x Column 12, where 0.364 is a factor that accounts for out-of-doors exposure time, non-uniformity of the ground surface and exposure while indoors with shielding from buildings.

Column 16: is the annual dose from atmospheric releases in adult members of the critical group ((Column 5 x Column 9) + (Column 5 x Column 13) + (Column 7 x Column 15)) (Sv/a/p).

Column 17: is the annual dose from atmospheric releases in infant members of the critical group (Column 5 x (Column 11 + Column 13) + Column 7 x Column 15) (Sv/a/p).

TABLE H3: DOSE FROM AQUATIC RELEASES - POPULATION AND POPULATION CRITICAL GROUP (Disk B:AECBHAM5, Rows 29-57)

This spreadsheet computes annual doses through aquatic pathways to the general population of Hamilton-Burlington and to individuals living in the critical group within the general Hamilton-Burlington population. The critical group is assumed to be exposed through consumption of fish from Hamilton Harbour contaminated by radioisotopes, as well as through consumption of the municipal drinking water.

Column 1: lists radioisotopes studied.

Column 2: indicates the waste streams (radioisotope sources), as foot-noted.

Column 3: is the rate of release of radioisotopes to Hamilton Harbour (Bq/s) from all sources (Table G11, Column 5 divided by 3.16E7 s/a).

Column 4: is the factor to account for dilution, dispersion, water treatment removal and radioactive decay between the point of release to Hamilton Harbour and drinking water derived from Lake Ontario (s/L).

Column 5: is the activity of radioisotopes in drinking water (Bq/L) (Table G11, Column 12).

Column 6: is the factor to account for dilution, dispersion and radioactive decay in Hamilton Harbour after release to the harbour from the WWTP's and from landfill sites (s/L).

Column 7: is the average concentration of radioisotopes in Hamilton Harbour (Table G11, Column 8/1,000 L/m^3; or Column 3 x Column 6).

Column 8: lists the bioconcentration factors, relative to water, to determine radioisotope concentrations in fish (L/kg).

Column 9: is the radioisotope activity in fish (Bq/kg) taken from Hamilton Harbour for consumption by the population critical group (Column 7 x Column 8).

Column 10: are the committed effective dose equivalent conversion factors for radioisotope ingestion by adults $(DCF)_i$ Ad, (Sv/Bq).

Column 11: are the transfer parameters relating $(DCF)_i$ Ad to dose in adults ($Sv \cdot a^{-1} \cdot Bq^{-1} \cdot m^3$) from drinking water contaminated by radioisotopes, assuming consumption of 1.95 L per day from the contaminated source (Column 10 x 700 L/a).

Column 12: are the committed effective dose equivalent conversion factors for radioisotope ingestion by infants $(DCF)_i$ Inf, (Sv/Bq).

TABLE H3: DOSE FROM AQUATIC RELEASES - POPULATION AND POPULATION CRITICAL GROUP (Disk B:AECBHAM5, Rows 29-57)

Column 13: are the transfer parameters relating $(DCF)_i$ Inf to dose in infants $(Sv \cdot a^{-1} \cdot Bq^{-1} \cdot m^3)$ from drinking water contaminated by radioisotopes, assuming consumption of 250 mL per day from the contaminated source (Column 12 x 90 L/a).

Column 14: are the transfer parameters relating $(DCF)_i$ Ad to dose in adults $(Sv \cdot a^{-1} \cdot Bq^{-1} \cdot kg^3)$ from consumption of fish contaminated by radioisotopes in Hamilton Harbour, assuming consumption of 5.5 kg/a of fish from the harbour (Column 10 x 5.5 kg/a).

Column 15: are the transfer parameters relating $(DCF)_i$ Inf to dose in infants $(Sv \cdot a^{-1} \cdot Bq^{-1} \cdot kg)$ from consumption of fish contaminated by radioisotopes in Hamilton Harbour, assuming consumption of 0.6 kg/a of fish from the harbour (Column 12 x 0.6 kg/a).

Column 16: lists annual doses (Sv/a/p) in adults of the critical group through aquatic pathways (drinking water plus fish consumption) (Column 15 x Column 11 + Column 9 x Column 14).

Column 17: lists annual doses (Sv/a/p) in infants of the critical group through aquatic pathways (drinking water plus fish consumption) (Column 5 x Column 13 + Column 9 x Column 15).

Column 18: lists the collective dose in the Hamilton-Burlington population (Sv/a) through aquatic pathways (drinking water only) (Column 5 x Column 11 x 525,000 people).

Column 19: lists the average per capita collective dose (Sv/a/p) (Column 19/525,000).

TABLE H4A: ANNUAL COMMITTED DOSE (Sv/a) TO SLUDGE WORKERS AT HAMILTON SEWAGE TREATMENT PLANT (Disk B:ACDSW)

Column 1: lists radioisotopes studied.

Column 2: dose conversion factor for inhalation (Sv/Bq).

Column 3: dose conversion factor for external cloud immersion ((Sv/a)/(Bq/m^3).

Column 4: dose conversion factor for gamma radiation from dewatering drum ((Sv/h)/(Bq/cc)).

Column 5: dose conversion factor for gamma radiation from sludge slurry tank ((Sv/h)/(Bq/cc)).

Column 6: dose conversion factor for gamma radiation from sludge on floor ((Sv/h)/(Bq/cc)).

Column 7: mass flow to sludge (Bq/a) (Table G2, Column 5).

Column 8: concentration factor in air (Bq/m^3) (Column 7 x 1.878E-11 m^3/a) (Report Table 8.3).

Column 9: concentration in sludge (Bq/cm^3) (Table G2, Column 13).

Column 10: dose from inhalation (Sv/a/p) (Column 8 x Column 2 x 2,000 h/a worked x 1.2 m^3/h breathed.

Column 11: dose from external cloud immersion (Sv/a/p) (Column 8 x Column 3 x 2,000 h/a worked/8,760 h/a).

Column 12: dose from dewatering drum (Sv/a/p) (Column 4 x Column 9 x 1,000 h/a).

Column 13: dose from slurry tank (Sv/a/p) (Column 5 x Column 9 x 1,000 h/a).

Column 14: dose from sludge on floor (Sv/a/p) (Column 6 x Column 9 x 2,000 h/a).

Column 15: total work time dose (Sv/a/p) (sum Columns 10 to 14).

TABLE H4B: ANNUAL COMMITTED DOSE (Sv/a) TO SLUDGE WORKERS AT BURLINGTON SEWAGE TREATMENT PLANT (Disk B:ACDSW)

Column 1: list of radioisotopes studied.

Column 2: mass flow in sludge (Bq/a) (Table 10B, Column 5).

Column 3: concentration in sludge (Bq/cc) (Table G10B, Column 10).

Column 4: concentration factor in air (Bq/m^3) (Column 2 x 1.878E-11 m^3/a).

Column 5: dose from inhalation (Sv/a/p) (Column 3 x Table H4A, Column 2 x 2,000 h/a exposed x 1.2 m^3/a respiration).

Column 6: dose from external cloud immersion (Sv/a/p) (Table H4A, Column 3 x Column 4 x 2,000 h/a exposed/8,760 h/a).

Column 7: dose from dewatering drum (Sv/a/p) (Table H4A, Column 4 x Column 3 x 1,000 h/a exposed).

Column 8: dose from sludge slurry tank (Sv/a/p) (Table H4A, Column 5 x Column 3 x 1,000 h/a exposed).

Column 9: dose from sludge on floor (Sv/a/p) (Table H4A, Column 6 x Column 3 x 2,000 h/a exposed).

Column 10: total work time dose (Sv/a/p) (sum of Columns 5 to 9).

TABLE H5A: ANNUAL COMMITTED DOSE (Sv/a) TO AERATION WORKER AT HAMILTON SEWAGE TREATMENT PLANT (Disk B:ACDAW)

Column 1:	lists radioisotopes studied.
Column 2:	dose conversion factor inhalation (Sv/Bq) (Column 12).
Column 3:	dose conversion factor external cloud immersion (Sv/a/Bq/m^3) (Column 13).
Column 4:	dose conversion factor for gamma radiation from aeration tanks (Sv/h/Bq/cc).
Column 5:	concentration in air (Bq/m^3) (10 x Column 6) (Report Table 8.3, Column 2).
Column 6:	concentration in sewage (Bq/cc) (Table G2, Column 12).
Column 7:	dose from inhalation (Sv/a/p) (Column 2 x Column 5 x 750 h/a worked x 1.2 m^3/h breathed).
Column 8:	dose from external cloud immersion (Sv/a/p) (Column 3 x Column 5 x 750 h/a worked/8,760 h/a).
Column 9:	dose from aeration tanks (Sv/a/p) (Column 6 x Column 4 x 750 h/a).
Column 10:	total dose (Sv/a/p) (sum Columns 7 to 9).
Column 11:	space
Column 12:	Table H1, Column 8 to accommodate two H-3 values for Column 2.
Column 13:	Table H1, Column 10 (see above).

TABLE H5B: ANNUAL COMMITTED DOSE (Sv/a) TO AERATION WORKERS AT BURLINGTON SEWAGE TREATMENT PLANT (Disk B:ACDAW)

Column 1: radioisotope list.

Column 2: concentration in sewage (Bq/cc) (Table G10B, Column 9).

Column 3: concentration in air (Bq/m^3) (Column 2 x 10).

Column 4: dose from inhalation (Sv/a/p) (Table H5A, Column 2 x Column 3 x 750 h/a exposed x 1.2 m^3/h respiration).

Column 5: dose from external cloud immersion (Sv/a/p) (Table H5A, Column 3 x Column 3 x 750 h/a exposed/8,760 h/a).

Column 6: dose from aeration tanks (Sv/a/p) (Table H5A, Column 4 x Column 2 x 750 h/a).

Column 7: total dose at work (Sv/a/p) (sum of Columns 4, 5 and 6).

TABLE H6: ANNUAL COMMITTED DOSE TO ASH LOADER AT SEWAGE TREATMENT PLANT (Disk B:ACDALSTP)

Column 1: lists radioisotopes studied.

Column 2: dose conversion factors for inhalation (Sv/Bq).

Column 3: dose conversion factors for external cloud immersion ((Sv/a)/(Bq/m^3)).

Column 4: dose conversion factor for gamma radiation from ash on the ground ((Sv/h)/(Bq/cc)).

Column 5: decay factor (Table G5, Column 4).

Column 6: concentration in STP incinerator air (Bq/m^3) (Column 8 x 2E-4 g/m^3 dust/1 g/cc waste density) (Report Table 8.3, Column 4).

Column 7: concentration in ash (Bq/cm^3) (Table G2, Column 14).

Column 8: concentration of ash on accounting for decay in storage pit (Column 7 x Column 5) (Bq/cc).

Column 9: dose from inhalation (Sv/a/p) (Column 2 x Column 6 x 1.2 m^3/h breathed x 250 h/a exposed).

Column 10: dose from cloud immersion (Sv/a/p) (Column 3 x Column 6 x 250 h/a exposed/8,760 h/a).

Column 11: dose from ash on ground (Sv/a/p) (Column 7 x Column 4 x 2.5E2 h/a exposed).

Column 12: total dose (Sv/a/p) (sum of Columns 9 to 11).

TABLE H7: ANNUAL COMMITTED DOSE (Sv/a) TO ASH TRUCK DRIVER AT HAMILTON SEWAGE TREATMENT PLANT (Disk B:ACDTDSTP)

Column 1: lists radioisotopes studied.

Column 2: dose conversion factor for inhalation (Sv/Bq) (Table H5, Column 2).

Column 3: dose conversion factor for external cloud immersion ((Sv/a)/(Bq/m^3)) (Table H5, Column 3).

Column 4: dose conversion factor for gamma radiation from ash in truck ((Sv/h)/(Bq/cc)).

Column 5: dose conversion factor for gamma radiation from ash on ground ((Sv/h)/(Bq/cc)).

Column 6: concentration in air (Bq/m^3) (Column 9 x 2E-4 g/m^3/1 g/cc) (Report Table 8.3, Column 4).

Column 7: sewage treatment plant decay factor (Table G5, Column 4).

Column 8: concentration in ash after decay in storage pit (Bq/cc) (Column 9 x Column 7).

Column 9: concentration in ash (Bq/cc) (Table G2, Column 14).

Column 10: dose from inhalation (Sv/a/p) (Column 2 x Column 6 x 1.2 m^3/h breathed x 500 h/a exposed).

Column 11: dose from external cloud immersion (Sv/a/p) (Column 6 x Column 3 x 500 h/a worked/8,760 h/a).

Column 12: dose from ash in truck (Sv/a/p) (Column 9 x Column 4 x 500 h in truck per year).

Column 13: dose from ash on ground (Sv/a/p) (Column 9 x Column 5 x 125 h/a in contact).

Column 14: total dose (Sv/a/p) (sum Columns 10 to 13).

TABLE H8: ANNUAL COMMITTED DOSE TO GARBAGE TRUCK DRIVERS IN HAMILTON (Rows 5-27) AND BURLINGTON (Rows 29-54) (Disk B:H8)

Column 1: lists radioisotopes studied.

Column 2: dose conversion factor for gamma radiation in truck from garbage ((Sv/h)/(Bq/cm^3).

Column 3: concentration in garbage (Table G7, Columns 7 (Hamilton) and 8 (Burlington) (Bq/cm^3) (linked via Column 7).

Column 4: dose (Sv/a/p) (Column 2 x Column 3 x 1.5E3 h/a).

Column 7: to accommodate duplication of Ni63 in Table G7.

TABLE H9: ANNUAL COMMITTED DOSE (Sv/a) TO GARBAGE COLLECTORS IN HAMILTON (Rows 5-27) AND BURLINGTON (Rows 29-60) (Disk B:H9)

Column 1: lists radioisotopes studied.

Column 2: dose conversion factor for gamma radiation from garbage ((Sv/h)/(Bq/cm^3).

Column 3: concentration in garbage (Bq/cm^3) (Table H8, Column 3).

Column 4: dose (Sv/a/p) (Column 2 x Column 3 x 1.5E3 h/a).

TABLE H10: ANNUAL COMMITTED DOSE TO TRUCK DRIVER AT HAMILTON TRANSFER STATION (Sv/a) (Disk B:H10)

Column 1: lists radioisotopes studied.

Column 2: dose conversion factor for gamma radiation from garbage in truck ((Sv/h)/(Bq/cc)) (Table H8, Column 2).

Column 3: concentration in garbage (Bq/cm^3) (Table H8, Column 3H).

Column 4: dose (Sv/a/p) (Column 3 x Column 2 x 1,500 h/a).

TABLE H11: ANNUAL COMMITTED DOSE TO LANDFILL SITE WORKERS IN HAMILTON (Rows 5-27) AND BURLINGTON (Rows 29-60) (Sv/a) (Disk B:H11)

Column 1: lists radioisotopes studied.

Column 2: dose conversion factor for inhalation (Sv/Bq) (Table H5, Column 2).

Column 3: dose conversion factor for external cloud immersion ((Sv/a)/(Bq/m^3)) (Table H5, Column 3).

Column 4: dose conversion factor for gamma radiation ((Sv/h)/(Bq/cc)).

Column 5: concentration in air (Bq/m^3) (Column 6 x 2E-4 g/m^3) (cm^3/g).

Column 6: concentration in garbage at landfill (Table G7, Column 18 (Hamilton) and Column 19 (Burlington)) (Bq/cm^3).

Column 7: dose from inhalation (Sv/a/p) (Column 2 x Column 5 x 1.2 m^3/h respired x 2,000 h/a exposed).

Column 8: dose from external cloud immersion (Sv/a/p) (Column 3 x Column 5 x 2,000 h/a exposed/8,760 h/a).

Column 9: dose from garbage (Sv/a/p) gamma (Column 6 x Column 4 x 2E3 h/a exposed).

Column 10: total dose (Sv/a/p) (sum Columns 7 to 9).

TABLE H12: ANNUAL COMMITTED DOSE (Sv/a) TO LOADER AT SWARU (Disk B:H12)

Column 1: lists radioisotopes studied.

Column 2: dose conversion factor for inhalation (Table H5, Column 2) (Sv/Bq).

Column 3: dose conversion factor for external cloud immersion (Table H5, Column 3) ((Sv/a)/(Bq/m^3)).

Column 4: dose conversion factor for gamma radiation from ash pile ((Sv/h)/(Bq/cc).

Column 5: dose conversion factor for gamma radiation from ash on ground ((Sv/h)/(Bq/cc)) (Table H13, Column 5).

Column 6: concentration in air indoors (Bq/m^3) (Column 8 x 1E-4 g/m^3 x 1 cm^3/g).

Column 7: concentration in air outdoors (Bq/m^3) (Column 8 x 2E-4 g/m^3 x 1 cm^3 g).

Column 8: concentration in ash (Bq/cc) (Table G7, Column 12) (linked via Column 15).

Column 9: dose from inhalation (Sv/a/p) (Column 2) x ((Column 6 x 1.2 m^3/h respiration x 1,500 h/a exposure) + (Column 7 x 1.2 m^3/h respiration x 500 h/a exposed)).

Column 10: dose from external cloud immersion (Sv/a/p) Column 3 x ((Column 6 x 1.711E-1 a) + (Column 7 x 5.7E-2 a)).

Column 11: dose from ash in pit (Sv/a/p) (Column 4 x Column 8 x 1.5E3 h/a).

Column 12: dose from ash on ground (Sv/a/p) (Column 5 x Column 8 x 500 h/a).

Column 13: total dose (Sv/a/p) (sum of Columns 9 to 12).

Column 15: Table G7, Column 12 to accommodate extra Ni.

TABLE H13: ANNUAL COMMITTED DOSE (Sv/a) TO TRUCK DRIVER AT SWARU (Disk B:H13)

Column 1: lists radioisotopes studied.

Column 2: dose conversion factor for inhalation (Sv/Bq) (Table H5, Column 2).

Column 3: dose conversion factor for external cloud immersion ((Sv/a)/(Bq/m^3)) (Table H5, Column 3).

Column 4: dose conversion factor for gamma radiation from ash in truck ((Sv/h)/(Bq/cc)).

Column 5: dose conversion factor for gamma radiation from ash on ground ((Sv/h)/(Bq/cc).

Column 6: concentration in air (Bq/m^3) (Column 7 x 2E-4 (g/m^3) (cm^3/g).

Column 7: concentration in ash (Bq/cc) (Table G7, Column 12) (via Column 14).

Column 8: dose from inhalation (Sv/a/p) (Column 2 x Column 6 x 1.2 m^3/h respiration x 1,000 h/a exposure).

Column 9: dose from external cloud immersion (Sv/a/p) (Column 3 x Column 6 x 1.0E3 h/a).

Column 10: dose from ash in truck (Sv/a/p) (Column 7 x Column 4 x 1E3 h/a).

Column 11: dose from ash on ground (Sv/a/p) (Column 7 x Column 5 x 2.5E2 h/a).

Column 12: total dose (Sv/a/p) (sum of Columns 8 to 11).

Column 14: Table 7.1, Column 12 (to accommodate Ni).

TABLE H14: ANNUAL COMMITTED DOSE (Sv/a) TO SORTER AT SWARU
(Disk B:H14)

Column 1:	lists radioisotopes studied.
Column 2:	dose conversion factor for inhalation (Sv/Bq) (Table H5, Column 2).
Column 3:	dose conversion factor for external cloud immersion ((Sv/a)/(Bq/m^3)) (Table H5, Column 3).
Column 4:	dose conversion factor for gamma from garbage on sorting conveyor ((Sv/h)/(Bq/cc)).
Column 5:	concentration in SWARU ash (Bq/cc) (Table G7, Column 12) (via Column 13).
Column 6:	concentration in air indoors (Bq/m^3) (Column 5 x 1E-4 (g/m^3) (dust/1 g/cm^3 density).
Column 7:	concentration in garbage (Bq/cc) (Table G7, Column 7) (via Column 14).
Column 8:	dose inhaled (Sv/a/p) (Column 2 x Column 6 x 1.2 m^3/h respired x 2,000 h/a exposed).
Column 9:	dose from external cloud immersion (Sv/a/p) (Column 3 x Column 6 x 2,000 h/a exposed/8,760 h/a).
Column 10:	dose from conveyor garbage (Sv/a/p) (Column 4 x Column 7 x 2E3 h/a).
Column 11:	total dose (Sv/a/p) (sum of Columns 8 to 10).
Column 13:	Table G7, Column 12 (to accommodate two Ni values).
Column 14:	Table G7, Column 7 (as above).

TABLE H15: ANNUAL COMMITTED DOSE TO LOADERS AT TRANSFER STATION IN HAMILTON (Disk B:H15)

Column 1: radioisotopes.

Column 2: dose conversion factor for gamma from garbage pile ((Sv/h)/(Bq/cc) (Table 8.2 in Report, list row (0.1 g/cc)).

Column 3: concentration in garbage (Bq/cc).

Column 4: dose (Sv/a/p) (Column 2 x Column 3 x 2,000 h/a).